Water Power

INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Electronic Computation

AS was pointed out on this page in our October 1954 issue*, there has been a growing necessity in practically all countries to integrate the operation of water-power plants with thermal stations to secure optimum overall economy. This process is not restricted to national boundaries and there has been a notable increase in transmission links between different countries.

In France, for example, there has always been a close co-ordination of hydro-electric and thermal generation, the north of the country being mainly thermal and the south mainly hydro. The interlinkage between the coal areas of Germany, Belgium and northern France is being carried out on an ever-expanding scale, and will no doubt lead ultimately to a considerable interchange of power between the predominantly hydro stations of Switzerland, southern France, Italy, and Austria, with the thermal plants of the north. In the United States, too, the engineers concerned with power transmission are now thinking in terms of 1,000-mile links—an aspect of American necessity which has only very recently come to the fore. In Canada large thermal stations are springing up in a land primarily dependent on water power.

The coming of nuclear power stations, with another and different set of characteristics, may still further complicate the problem of integrating power systems of differing types.

In view of these developments new thought may well be needed, by both thermal and hydro-electric engineers, to obtain the best possible efficiency from all types of power-generating plant. In the past, as we saw recently when we spent some time at the National Control Centre in Britain, the planning of system operation on a thermal basis is carried out first by long-term plans for siting the power plants near to the coalfields, since the transport of energy over grid wires is nowadays considered cheaper, for distances of about 50 miles or more, than any other form of transportation, whether this consists of carrying coal by rail or by sea, or by pumping oil through a pipeline. The system planners must provide adequate transmission capacity, and it is to this end that in Great Britain it has been decided to construct a 275 kV supergrid. Coming to the more immediate problems facing the system control engineers, they have to ascertain the probable load within the next load-determination period, say 24 hours, and then allot loads to the various stations on the basis of giving the greatest load to the most efficient station, the next greatest load to the next most efficient station, and so on, leaving the least efficient station to take care of the peaks.

The hydro-electric engineer, on his part, as exemplified perhaps in the most typical fashion by the system control at Trollhättan in Sweden, is concerned with an entirely different set of problems. He has to regulate lake levels for purposes other than power generation, he has to provide compensation water for irrigation and amenity purposes, and he has so to adjust the output from his various plants as to leave water in store at the right places, for use at the right time. He is not primarily concerned with saving the last drop of water at, for example, a run-of-river plant, whereas the engineer concerned with operating a thermal network should always endeavour to save the last pound of coal.

In many countries these problems have been thrashed out mainly on an empirical basis and on a small scale, but in the large-scale schemes of integration between hydro and thermal stations of which we are speaking the problem of correlation becomes too difficult for ready analysis. In such cases the electronic computer, now increasingly used for highly complicated calculations in many industries, may well prove an asset. A suitable computer would enable solutions to be reached automatically as to the best loading arrangements at any given instant. Indeed, only a computer can make lightning calculations with absolute accuracy when presented with the large number of variables that occur in an extensive system at any particular time—for example, coal costs at various thermal

* "Alternative-Power Economics," page 361.

power stations, efficiencies at those stations at various loads, transmission capacities, storage levels in half-a-dozen different reservoirs, rates of river flow under varying forecasted meteorological conditions, cost and availability of energy for pumped storage, and many other factors.

For security of supply, as well as for both short-term and long-term economy, the time may have come when a single human brain can no longer be expected to provide the correct answer at all times, and the expansion of supply systems would seem to make it increasingly desirable that operating engineers, both thermal and hydro, should consider this new aid to system analysis.

Newfoundland Survey

A SURVEY for what may prove to be one of the largest hydro-electric schemes in the world is now being conducted on the Hamilton River, Labrador, by British Newfoundland Corporation Limited. This Corporation has been granted by the Government of Newfoundland the largest Canadian concession since the Hudson Bay concession was awarded in the reign of Charles II, and is empowered to explore, and if warranted to develop, the water-power, mineral and timber resources on territory up to 50,000 sq. miles in Labrador and 10,000 sq. miles in the Island of Newfoundland.

Investigations to date have proved the existence of an immense source of power at Grand Falls on the Hamilton River, where a head of at least 1,000 ft. can be utilised, and a completely uninhabited catchment area the size of Wales can be impounded. Preliminary estimates place the potential capacity at three million horsepower. Seeing that the project is as yet in the survey stage no decisions have yet been made as to whether to develop the site, and if so, what should be the size of the development, but an initial development of one million horsepower is being considered, which may cost between 150 and 250 Canadian dollars per horsepower installed, and which may commence operation some time between 1962 and 1965. No anxiety is felt as to the disposal of this huge block of power, for it is considered that eastern Canada will still be power-hungry even when the St. Lawrence scheme is completed.

The British Newfoundland Corporation Limited is an Anglo-Canadian combine financed by private-venture capital. Its shareholders comprise nearly thirty British and Canadian companies, headed by N. M. Rothschild & Sons, Bowater Paper Corporation Limited, Anglo-Newfoundland Development Co. Ltd., Anglo-American Corporation of South Africa Limited, Rio Tinto Co. Ltd., Frobisher Limited, and The English Electric Co. Ltd. Included among the other shareholders are Odhams Press Limited, the proprietors of this journal. The Chairman is Mr. B. C. Gardner, M.C., Chairman of the Bank of Montreal, and the Managing Director Mr. A. W. Southam, C.B.E.

New Zealand Demand

BY March 1958, New Zealand's North Island demand for electric power will have increased by 11 per cent. compound a year; in the Nelson-Marlborough district demand will increase by 9·6 per cent.; and in the rest of the South Island by 7·1 per cent. a year. These estimates are given in the recent report of the Electrical Supply Authorities Association. A committee, which worked in collaboration with representatives of the State Hydro-Electric Department, was set up following a request by the general manager of the Department at Dunedin last year. The chairman of the E.S.A.A. said that in the past the association had tried to measure power generating needs; now it had presented a report on possible consumer demand over a five-year period. He considered that the position in the North Island called for faster development of the hydro-electric schemes on the Waikato river and development of geothermal steam resources.

Cuban Six-River Scheme

FROM Havana it is reported that Cuba is planning to harness the power of six of its rivers to produce cheap electricity for the benefit of agriculture and industry. At a ceremony of formal signature, the first Cuban hydro-electric authority (PRICHEC) was legally constituted by the Agricultural and Industrial Development Bank of Cuba. Creation of PRICHEC has been authorised by a 1953 decree, which granted the bank exclusive and perpetual rights to exploit the waters of the rivers Hanabanilla, Guanayara, Negro Jibacoa, Pretiles, and Boquerones. Following the signing, contracts were signed with the Knappen-Tibbets-Abett-McCarthy firm of New York to draw up plans for the hydro project and to supervise its construction. Preliminary studies indicate that the rivers could be used to build plant capable of producing 224,000 kWh daily.

Spanish Schemes in Progress

A NUMBER of important power developments are in course of construction by Fuerzas Electricas de Cataluña, S.A., in the region of the high Garona, where 29 lakes lying at an altitude of over 2,000 m. in the Pyrenees are in course of regulation. Of these lakes the most important are those of Mar, Rius and Tort, with an aggregate useful storage of 21 million cu. m. The waters from these lakes converge on Artías, at the head of the Arán Valley, where a development is under construction which will regulate the flow to a series of stations in the valley. Of these stations, Viella, Benós and Cledes are in operation, and work is in progress on stations at Barradós, Bosost and Jueu in addition to Artías.

Artías station will utilise a head of 802·6 m. and will have a capacity of 72 MVA in two units, each comprising two Pelton wheels at either end of a 36 MVA horizontal alternator. Water from the lake system will be carried by a main canal 9·9 km. long, supplemented by 7·21 km. of auxiliary canals, leading to a penstock 1,990 m. long, of an internal diameter ranging from 1·8 to 1·4 m. and weighing 1,692 metric tons. The surge chamber will have a volume of 12,000 cu. m. There will also be a 10 MVA pumping station at Restanca transferring surplus water from lakes in the Colomés region to lake Mar against a head of 284·5 m.

On the river Barradós a dam 12 m. long and 4 m. high, with a spillway 2 m. wide, will divert water through a tunnel 5·6 km. long designed for a flow of 3 cu. m. per sec. and leading to a 4,000 cu. m. surge chamber and to a penstock 1,600 m. long, 1 to

0·8 m. in diameter and weighing 650 tons. The station will be at Benós, where a single vertical-shaft Pelton set of 16·5 MVA capacity will be installed.

At Bosost a dam is being built on the river Garona 23 m. wide, having three spillway sluices 6 m. wide and a scour sluice 1·5 m. wide by 2·8 m. high. A tunnel 6 km. long, designed for a flow of 23 cu. m. per sec., will lead to a 5,000 cu. m. surge chamber and to a penstock 175 m. long, 2·5 m. in diameter, and weighing 172 tons. Two vertical Francis sets will be installed here, each rated at 11 MVA at a head of 103 m.

The development at Jueu is still in the blueprint stage, but this will supply a 20·5 MVA set installed in Benós station.

In the Segre basin a 7·5 MVA station is under construction at Balaguer, and stations are to be built at Termens (12 MVA) and Lérida (12·3 MVA).

Two large schemes are in the design stage for the basin of the Ebro. At Mequinenza a 280 MVA station is to be built consisting of four sets operating on a head of 60 m., and at Fayón there is to be a 68 MVA development comprising four sets working at a head of 14·45 m.

St. Lawrence River Models

IN their autumn Quarterly Bulletin of the Division of Mechanical Engineering, the National Research Council of Canada report progress on two models of sections of the St. Lawrence River to determine the effect of proposed construction work on the current distribution and water levels in the river. One of these models—that of the Cornwall Island section—has been completed and has been verified for low, medium and high discharge conditions and the test programme started. To facilitate construction and to allow extensive changes to be made, the model was made by assembling a number of pre-cast concrete blocks 2 ft. square and cast from patterns made directly from the contour map of the river. The model represents about nine miles of river to a scale of 1: 480 horizontal by 1: 96 vertical.

The second model, covering the Galop Island section—a distance of about nine miles between Prescott and Cardinal—is now under construction and will be to a scale of 1: 240 horizontal by 1: 48 vertical. Its construction will be similar to that of the other, but owing to its large size the concrete blocks are being made 2 ft. by 4 ft.

Short-wave Radio for Repair Gangs

THE North of Scotland Hydro-Electric Board are carrying out tests to find the best sites for short-wave radio stations which will enable their local headquarters to keep in touch with repair and maintenance gangs working on transmission and distribution lines. The first stage in the use of short-wave radio by the Hydro-Electric Board will be brought into operation this winter. The Board are installing short-wave radio sets in two small buildings erected near the top of the 2,500 ft. high Corrieyairack Pass to store transmission-line spares and provide overnight shelter for repair gangs working on the new 132 kV transmission line over the Pass from Fort Augustus to Glen Truim, near Newtonmore. Two repair vans will be equipped with radio so that communication can be maintained from both the north and south sides of the Pass. Walkie-talkie equipment will be carried also by the repair gangs to enable them to speak to either the vans or the huts at the top of the Pass.

It is hoped by the Board that the use of radio in other areas also will speed up the direction of vehicles and repair gangs to overhead-line breakdowns, particularly during gales and snowstorms when telephone lines may also be down, and, when gangs are working in isolated areas far from their bases, make the most efficient use of men and equipment and reduce unnecessary journeys. Radio equipment would be installed in the Board's repair vehicles and men patrolling lines over the hills would be able to keep in touch with the vehicles by the use of walkie-talkie apparatus.

Tests are being made in the Board's Northern, North Caledonia, Aberdeen, and South Caledonia areas covering the Northern, North-East and Central Highland counties. During experiments of transmitting messages from a hill near Dingwall, signals were received clearly at places as far away as Achnasheen, Inveran (Sutherland), Dornoch, Fasnakyle in Glen Affric, Carrbridge and Boat of Garten.

Indonesia Speed-up

THE construction of Djatiluhur Dam, on the Tjitarum River, which will be the biggest in Indonesia, is now likely to be finished in five years instead of ten as originally projected. Nine engineers from abroad have been engaged to supervise the work, which has already begun. Hydro-electric power will be generated to supply all West Java.

International Symposium on Scientific Research

THE problems of organisation and administration of scientific research in Europe was studied by highly qualified European specialists at an international symposium held at the University of Nancy in October. The symposium was organised by the European Productivity Agency of the O.E.E.C. and the Rector of the University of Nancy, who acted as Secretary-general, with the assistance of the French Ministry of Industry and Commerce. It followed up a first international study session convened by the O.E.E.C. in London in November 1952, as the result of a technical assistance mission which studied the organisation of research in Europe.

The aim of this international symposium was to enable representatives of government bodies, university teachers and European industrialists to study the progress achieved by member countries in the administration and organisation of scientific research, and means of developing co-operation for the furtherance of applied research between national bodies, industries, and higher educational establishments. It was intended also to encourage closer relationships between experts dealing with a subject considered to be of increasing importance by all countries.

Delegates from Austria, Belgium, France, Germany, Italy, the Netherlands, Norway, Sweden, and the United Kingdom attended the symposium, and the United States, Australia, Canada, India, New Zealand, the Federation of Rhodesia and Nyasaland, and the Union of South Africa were represented.

Book Reviews

Dams and Control Works. Third Edition, 1954. U.S. Bureau of Reclamation, Denver Federal Center, Denver, Col. (Attention 841). Copies are also obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D.C. 218 pp. Many illustrations. Price $2.75.

The previous edition of this publication appeared 15 years ago, and in the new edition the presentation has been simplified to widen the range of interest and to increase the ease with which major design features can be studied. The result is a volume that is eminently readable and full of interest.

By the end of 1952 the Bureau of Reclamation had 47 power plants in operation or on maintenance status, and had itself constructed 36 of these plants. Five times within its history the Bureau was called upon to design and build a dam that at the time was higher than any then in existence in the world. The Bureau's experience as enshrined in this book, therefore, cannot fail to be of interest and profit to all engaged in dam design.

Most of the book is occupied by illustrated descriptions of 22 dams, including such famous structures as Hungry Horse, Grand Coulee, Hoover, and Shasta, and special articles, written by members of the staff, are devoted to the design of dams and to reservoir outlets and spillway gates. A preliminary article gives an informative summary of the scope of Reclamation engineering.

Rules for the Unit Testing of Circuit Breakers for Making Capacity and Breaking Capacity. (ASTA No. 15). The Association of Short-Circuit Testing Authorities, 36 Kingsway, London, W.C.2. Price 10s.

The steady increase in the ratings of high-capacity circuit breakers has for a long time posed the problem of providing adequate testing plant, and circuit-breaker design has now reached a point at which it is uneconomic to build equipment capable of full-capacity testing. Testing with reduced recovery voltage cannot be regarded as fully satisfactory. Fortunately the present tendency towards designs incorporating a number of identical breaking units in series has made it possible to develop a technique of unit testing whereby the performance of the circuit breaker as a whole can be assessed from the behaviour of a single unit.

The Rules for Unit Testing now published embody the experience gained in ASTA testing stations, and future ASTA certificates will be issued in accordance therewith. These Rules may well serve as a model for the drafting of international regulations.

Statistical Year-Book of the World Power Conference, No. 7. Published by Lund Humphries & Co. Ltd., 12, Bedford Square, London, W.C.2, on behalf of The Central Office of The World Power Conference. Price £2 net. Postage 1s. 6d.

The latest edition of this invaluable work of reference contains annual statistics of fuel and power production, distribution, and consumption for the years 1950-1952, with some supplementary and revised figures for earlier years and available statistics for 1953. In the section on water power it is stated that reported gross capacities at 100 per cent. efficiency of all sites surveyed, whether developed or undeveloped, measured at arithmetical mean flow, amounted to a world total of about 450 million kW. Of this total, about 160 million kW were in Africa, 150 million kW in North America, 30 million kW in Asia, 85 million kW in Western Europe, one million kW in Eastern Europe (excluding the U.S.S.R.) and 6 million kW in Oceania. Of this world total about 67 million kW, or 15 per cent., were reported as having been developed. As in previous issues, tables show the water power resources and the developed water power for each country for which figures are available, and an interesting table shows the rate of increase of installed capacity in the various countries.

Irrigation in Hungary. Hungarian News and Information Service, 33, Pembridge Square, London, W.2.

A neatly produced and attractively illustrated paper-backed booklet gives a picture, in excellent English, of the progress made with Hungary's irrigation projects. Naturally the Tiszalök combined power and irrigation scheme occupies an important place in the description of this country's achievements.

B.S.I. Annual Report for 1953-54. Published by the British Standards Institution, British Standards House, 2 Park Street, London, W.1. 200 pp. Price 5s.

This report evidences the remarkable comprehensive range of industries which now use the B.S.I. facilities to prepare agreed standards for their products and services. Standardisation projects undertaken and completed during the year under review cover some sixty major industries, and the record is made of several thousands of items which are in various stages of development, from the initial idea to the preparation of new or revised drafts.

A separate special section records a total of over 100 subjects in which international alignment of standards is being prepared through the International Organization for Standardization (ISO) and the International Electrotechnical Commission (I.E.C.), and some 70 pages are devoted to lists of the members of the principal Councils and Industry Standards Committees working within the B.S.I.

The work of the Institution has been greatly increased in efficiency by the facilities afforded by its new premises at 2, Park Street; the number of new and revised standards issued during the year to 31st March was 286, as compared with 260 in the preceding year, and copies of British Standards sold reached 914,000 as compared with 872,000. Of this total about a quarter are sold overseas. Subscribing members of the Institution now exceed 8,000, their contributions in the year totalling over £110,000. It has now 2,388 standing committees, on which 14,000 technologists and specialists from industry and the professions serve.

The English Salvi Company. This company has been incorporated as a private limited company, in Britain, and its objects are to manufacture and sell, in association with the Salvi Company of Milan, in Great Britain and the Commonwealth and Colonial Territories (excluding Australia and New Zealand) the whole range of compression joints and dead-ends, spacers, substation fittings, and compressors, used on high-voltage overhead transmission lines, as designed and made by A. Salvi & Company of Milan, Italy. The company is arranging manufacturing facilities near London, and its office has been established at 11 Kensington Church Street, London, W.8.

Clowhom Plant

At Clowhom Falls the British Columbia Power Commission have erected an interesting hydro-electric station to serve an isolated community.

WITH a capacity of only 4,000 h.p. the installation at Clowhom Falls may be small when compared to the enormous plants that are usually associated with Canadian practice, but it is none the less interesting on that account, and performs a very necessary service to a relatively isolated coastal area, some 40 miles north of Vancouver, which can only be approached by air or sea. The site has been recognised as a good one for power development for many years, and was utilised as long ago as 1890 by a milling company, who erected a plant to deal with the cedar logs floated down from the upper Clowhom Lake. A log dam was sufficient for this early development, but in 1908 this structure was replaced by a concrete structure, the materials for which were transported from Vancouver by scow. A 90 ft. waterwheel supplied the main power requirements of the mill, which was mainly concerned with making shingles, and a small Pelton wheel served to drive a generator for the electric lighting load. This plant is still in operation although the mill ceased to work in 1927, the waterwheel being used to operate a car on an inclined railway track for the transport of supplies to the townsite, while the Pelton still supplies the local lighting services. Since the mill closed down the site has become a popular fishing resort.

Engineers from the British Columbia Power Commission surveyed the site in 1948, and found the north pier and wingwall of the old concrete dam to be in a perfectly sound condition, and both these components were incorporated in the new intake structure, the erection of which was begun towards the end of 1950. A good stable run off is assured as a substantial portion of the summer flow is derived from the melting of glaciers.

After leaving the lake, the river divides to form twin falls, and the power house, surge tank and transformer yard are constructed on the resulting island. The present plant consists of two 1,875 kVA 0·8 power factor, 60 cycle, 4,160 V Bepco alternators built by Bruce Peebles & Co. Ltd., of Edinburgh, driven by spiral-cased Francis turbines supplied by the Vancouver Engineering Works to the design of The Pelton Water Wheel Company, Inc., of San Francisco. Provision has, however, been made for the installation of two further units to bring the total installed horsepower to 12,000. Each turbine is rated at 2,000 h.p. at 600 r.p.m., 160 ft. head, but is at present operating on a head of 125 ft. only.

The station is designed to operate unattended, and is equipped with a comprehensive scheme of protective devices, although normally a resident operator is available to make daily inspections and to take care of any emergency that may arise. The units are started and synchronised manually, but under fault conditions an alarm is sounded both in the station and the operator's cottage, and the turbines are shut down automatically. These protective devices operate under conditions of overspeed, undervoltage, and defective oil pressure. The station supply service is taken directly from the busbars, and is protected by high-rupturing-capacity fuses, equipped with alarm contacts. Other protective items, fitted into the generators themselves, include temperature indicators embedded in the stator cells, and bearing thermometers with over-temperature contacts.

The switchboard, supplied by Bepco Canada

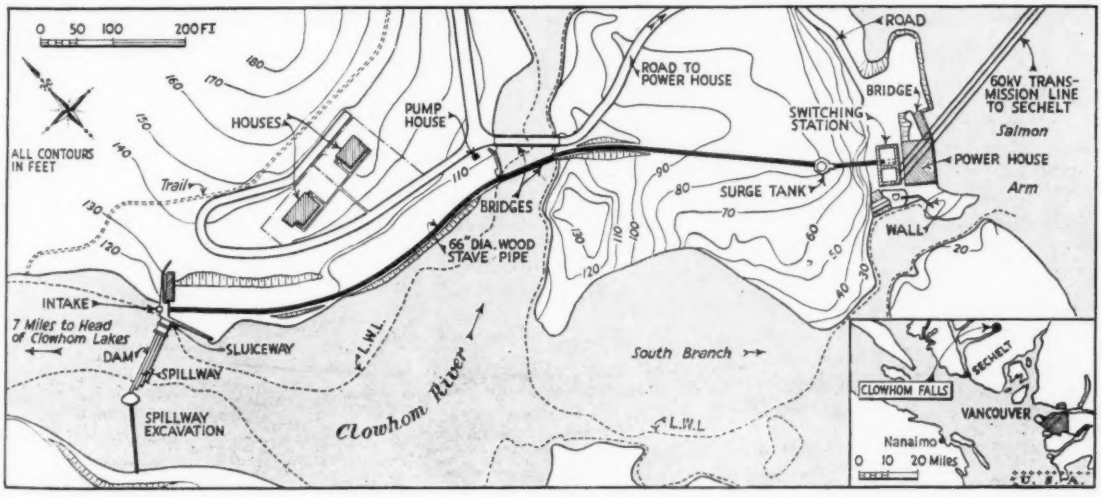

Fig. 1. Sketch map showing general features of Clowhom scheme

Fig. 2. General view: Clowhom powerhouse and surge tank

Limited, is of the enclosed cubicle type having non-withdrawable circuit breakers. All protective relays are accommodated on the switchboard, and horizontal single-break low-oil-content circuit breakers with an interrupting capacity of 150,000 kVA at 4,160 V are installed. Access doors are provided at the front and rear, with operating and metering equipment mounted on the front, and protective relays on the rear panels. The installation is very compact, but easily accessible. The transformer yard contains four 1,250 kVA Maloney units, one of which is spare, stepping up to 66,000 V.

From the power station a 22·5 mile transmission line carries the power at 66 kV to Sechelt, where formerly a small diesel plant was located. The poles for the transmission line had to be placed on precipitous rocky slopes, necessitating the compressors and winches being mounted on rafts and "snaking" the

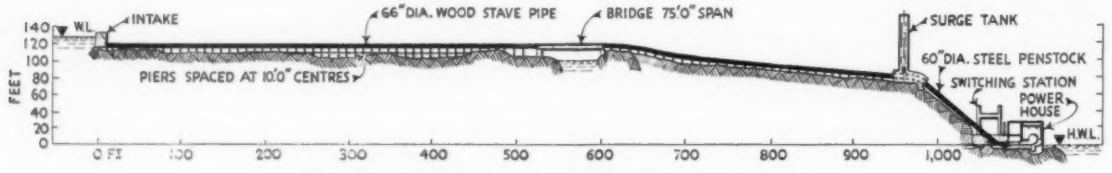

Fig. 3. Sectional elevation along Clowhom pipeline

Fig. 4. Concrete dam, spillway and intake structure

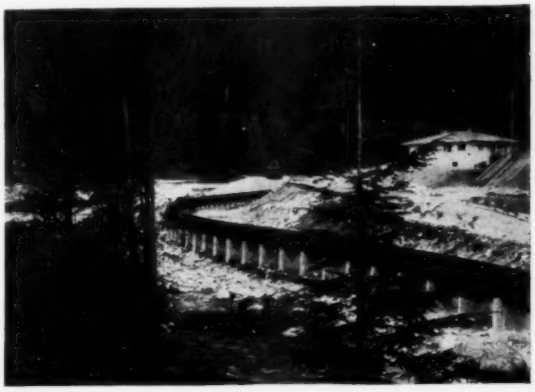

Fig. 5. Part of 66 in. dia. wood-stave pipeline mounted on concrete pillars

poles out of the sea with a raft-mounted gin pole. Towards Sechelt it was necessary for the line to cross over a mountain pass, and the construction crew had to put in a day's work climbing before actually getting to the task. These men toiled through heat and dust, mud and rain, cold and snow, and surmounted untold difficulties, not the least of which was the breakage of cables used for hauling the equipment up precipitous slopes. The wood-pole transmission line carries 2/0 ACSR 6/1 stranding conductors 0·447 in. in diameter.

An important factor which had to be taken into account in the selection of a suitable voltage regulator for the alternators was the possibility of operating the station at no-load with the 66 kV line connected. The calculated charging current of the ultimate 66 kV system corresponded to approximately 1,300 kVA, which represents an appreciable fraction of the alternator capacity. When an alternator has to provide current at a low leading power factor, the generated voltage tends to rise, due to armature reaction, unless the field excitation is reduced. In exceptional cases it may even have to be reversed. Calculations showed that reversal of field excitation would not be necessary, but that a high range of excitation control would be required for this purpose. This could only be accomplished economically by a potentiometer type of controller.

A further feature of these generators is that the rotors are each machined out of a solid steel casting, with integrally cast poles. This solid pole is completed with a bolted-on pole tip, which, with a special process of heating and compression of the pole windings, gives a very high factor of safety under overspeed conditions. Both turbine and generator are designed for an overspeed of 86·5 per cent., or 1,120 r.p.m., and overspeed switches provided with the generators are arranged to trip the governor shutdown at 125 per cent. rated speed, and to close the butterfly valve at 140 per cent. rated speed.

A further advantage of the solid rotor construction is the high damping effect obtained with the solid poles, which obviates the necessity of an amortisseur winding. In this case the high line-charging requirement was a distinct advantage in maintaining stability of operation.

Generators as large as 30,000 kVA have been constructed using this type of rotor design, the same anti-hunting characteristics being maintained irrespective of size.

The dam is a concrete gravity structure having a maximum height of 18 ft. and a length of 90 ft. It is provided with two stop-log sluices, and incorporates the intake, which is protected by a training wall. As is usual in a relatively small scheme of this kind in Canada, the pipeline is of the wood-stave type, supported on wood and concrete cables. It is 933 ft. long,

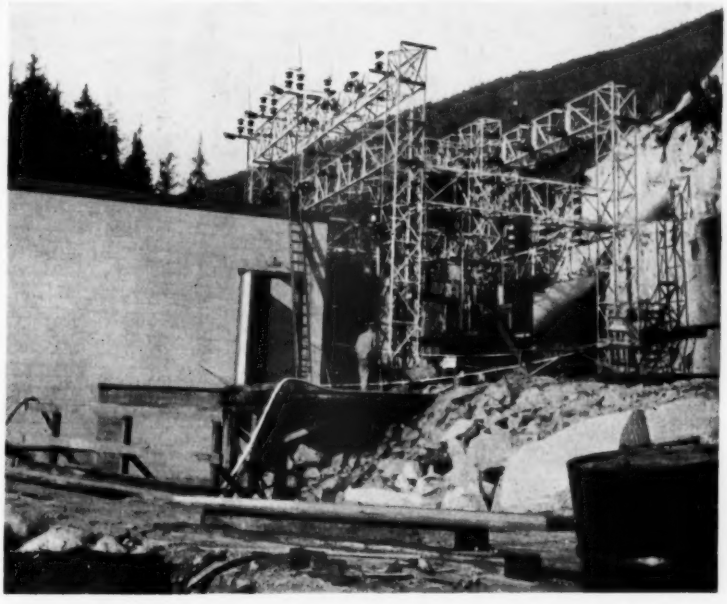

Fig. 6. Transformer yard and switching station between powerhouse and rock face

66 in. internal diameter, and designed for a head of 115 ft. The shell thickness is 2½ in., and the staves are reinforced by 59,400 lb. of steel banding. It is pressure impregnated with creosote, and was manufactured by the Pacific Coast Pipe Co. Ltd.

The surge tank is of the simple type, constructed of steel, and is 12 ft. in diameter and 69 ft. high. It is mounted on a concrete foundation and was built, together with the steel penstock, by the Dominion Bridge Company. The penstock has a length of 146 ft. 6 in. and is 5 ft. in diameter.

Dawson, Wade & Company were the general contractors for the scheme, and the heavy transportation work—a somewhat formidable task—was undertaken by Arrow Transfer Limited, of Vancouver.

The Clowhom Falls development is the third hydro-electric project constructed by the British Columbia Power Commission since its inception in 1945. Since that time the Sechelt area has been serviced by the Commission, starting with 337 customers, and increasing to 1,312 during the intervening years. The load during the same period almost quadrupled, increasing from 453,268 to 1,744,177 kWh per annum. It is thus obvious that the Commission have shown a great deal of foresight in pushing forward with this project, which utilised an asset whose value will inevitably increase as the years pass on.

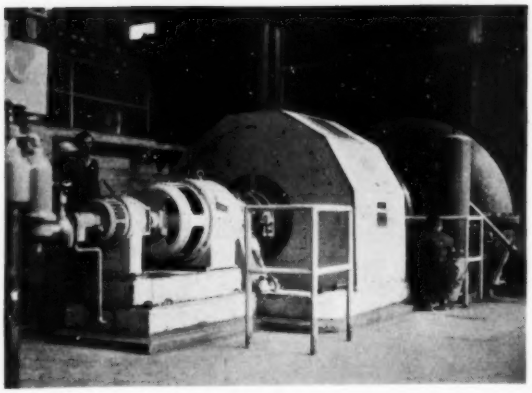

Fig. 7. Interior of powerhouse showing one of the two 2,000 h.p., 1,875 kV A turbine generating sets

In conclusion, we have pleasure in acknowledging the courtesy of the staff of the British Columbia Power Commission in allowing us to publish these notes, and for their kindly reception of us during our visit.

Earth-Moving Machinery Lubrication

In the pick and shovel days the power component of earth-moving equipment was customarily lubricated by a variety of malt liquors, of which satisfaction or criticism could be expressed with a minimum of literacy; and generally was. Nowadays the subject has been elevated out of this non-literary rut and books can usefully be devoted to it. Such a book has reached us from C. C. Wakefield & Co. Ltd., and can be thoroughly recommended to those who have modern earth-moving machinery under their care. Apart from the wealth of detailed information it gives about the construction and handling of the various types of earth-moving machines now employed, great care has been taken by the technical author to give reasons for his statements. Thus the operator is not left with a blunt instruction to follow a certain course of action but is given an explanation as to why it is desirable and how it will make his work easier, less subject to irritating delays and therefore more efficient. The book contains 64 pages and is excellently produced and illustrated. Chapters are devoted to machinery bearings, transmission gears, wire ropes and lifting chains, hydraulic equipment, compressed-air equipment, diesel engines, petrol and paraffin engines, storing problems, typical troubles, to the firm's lubricating specialities and to the grades of oil to use for specific purposes.

40 Jahre Kaplanturbinen (Forty Years of Kaplan Turbines). By Dr. Ing. H. F. Canaan and Chief-Engineer L. Meissner. This abundantly illustrated brochure has been published by the J. M. Voith Engineering Works, of Heidenheim (Brenz), Würtemberg, in commemoration of the fortieth anniversary of the granting of patent rights in Germany to Professor Viktor Kaplan for his runner-blade adjusting gear in rotary machines. The theoretical and practical development of this now universally known improvement of the old propeller turbine is described and discussed at length in separate chapters. The extent of the progress accomplished in the construction of Kaplan turbines in the short span of hardly thirty years, is strikingly demonstrated by a comparison of the characteristics and diagrams of the first unit that left J. M. Voith's workshops in 1922, and of some of their latest achievements. The brochure closes with an interesting chapter on speed regulation in Kaplan turbines.

Pneumatic Valve Control. Two leaflets from Telektron (Great Britain) Limited, 7, Chesterfield Gardens, London, W.1, describe a new system of pneumatic remote control for valves, and polythene flexible compressed-air tube for use therewith.

Aluminium for Insulated Electric Cables. This is the title of a most interesting Development Bulletin published by Aluminium Union Limited, The Adelphi, London, W.C.2, on a subject of increasing importance to electrical engineers. After an introductory section on the basic properties of aluminium, major sections follow on cable sheaths and on aluminium conductors. Aluminium wire armour is then considered, and brief descriptions are given of miscellaneous types of cable and accessories.

G.E.C. Research, Development, Achievement. A 52-page brochure under this title gives some idea of the bewildering variety of interest and achievement in the electrical field that comes within the purview of this famous firm. The brochure covers many subjects, from Power Generation to Powder and Light, and from Synthetic Crystals to Safety by Night, but even so, we have reason to believe that the tale is not complete.

Principles of Tunnel Blasting

The principles underlying placing of holes, construction of drilling and ignition patterns and smooth blasting are discussed. Special attention is devoted to conditions for parallel-cut blasting. A statistical analysis shows how drilling scatter limits the average advance, but a substantial increase in this advance can be achieved, with both wedge-shaped and parallel placing of holes, by precision drilling, large drill holes and exactly-determined sequences of ignition.

By ULF LANGEFORS

PART ONE

IN blasting technique, a special interest is at present being devoted to the question of blasting drifts and tunnels. This is not only because there are still numerous unsolved problems and unexplored possibilities in this sphere, but also because of the enormous scope that the underground building programme has assumed. The discussion about tunnel blasting has thereby gained exceptional importance and become of current interest. It would not appear to be too daring to anticipate that, during the next few years, we may expect a vast development in blasting and drilling methods, and final results which it would only a few years ago have seemed unrealistic to forecast.

To clarify the prerequisites for such a development, an account is given here of principles and calculations for tunnel blasting, conditions for the application of these calculations in practice, analyses of different types of cuts, construction of drilling patterns and finally the principles of smooth blasting.

Questions connected with this matter have been the subject of detailed study at the Detonation Laboratory of the Nitroglycerine Co. Ltd., at Vinterviken, near Stockholm. This study has covered questions bearing on basic principles and methods of calculation as well as full-scale application. These investigations have been carried out in extensive collaboration with other organisations, especially the Stockholm Harbour Board, Widmark and Platzer Co. Ltd., the Royal Fortification Administration and the Atlas Diesel Co. Ltd. The Hellefors Works have also made important contributions to a practical solution of the problem by large-hole drilling.

Results With Free Burdens

Far more explosive per cubic metre of rock is generally used for tunnel blasting than is required, for example, for bench blasting. It is natural to assume that this difference is caused by the degree of fixation, and it is at once obvious that bench blasting with free faces is an optimum case. The conditions which here determine the result of the blasting have been dealt with by the author in a previously published work, "Calculation of Charges for Bench Blasting"[1]. From this have been taken the values for maximum burdens which apply in respect of normal rock, explosive LFB, degree of packing = 1 kg. per cu. cm. (Fig. 1). The value $c=0{\cdot}4$ on the factor of the rock is intended to cover a normal variation in the rock, not on the other hand major mistakes in the placing and direction of holes. When drilling the pattern, the degree of scattering of the drill holes must be noted and the burden correspondingly reduced, as indicated by the curves in Fig. 1 with drilling deviations of 0·15 and 0·30 m.

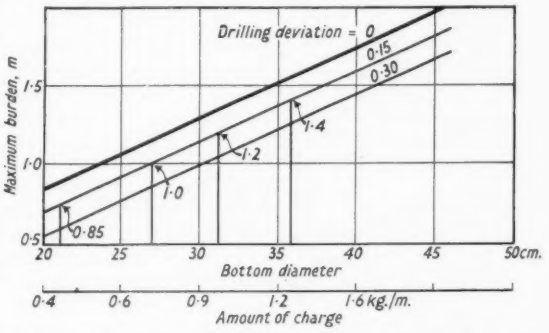

Fig. 1. Maximum burden as a function of diameter of drill hole at bottom and drilling scatter. Rock constant c=*0·4. Explosive LFB, degree of packing =1·0 (normal case)*

The actual nature of the break with free burdens appears from Figs. 2*a* and *b* which show the two main cases to be taken into account, first with free bottom, secondly with fixed bottom. In both cases the angle of breakage α_u will be about 90°. In the case of free bottom, the bottom angle α_b will be about 135°. If the bottom is fixed, as is the case in bench blasting and very often in stope blasting, the break at the bottom must follow another surface. The angle can then be between 90 and 135 degrees dependent on charging and depth of drill hole. If the instructions in Ref. 1 are followed, the bottom angle will be about 90°. Smaller angles can only be expected under special circumstances, and then only for a considerably smaller angle of breakage, as is indicated by the lined sections in Fig. 2*b*. If the drilling pattern is drawn up on the basis of 90° angle of breakage, it can be expected that tearing at the bottom will take place perpendicularly to the drill holes, and not, as is often stated, with a bottom angle of less than 90°. The rules which apply for bench blasting can thus be adopted, and as long as the construction can be used, one has

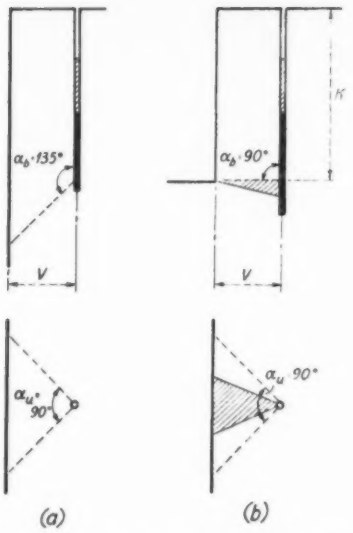

Fig. 2. Natural angles of breakage with free burden; (a) *free bottom,* (b) *fixed bottom,* K *height of bench,* V *burden*

the most favourable case from the blasting aspect. A study of the conditions for tunnel blasting shows that from this basis the effects of various factors can be mathematically controlled. Even when blasting the cut, in important cases from the very beginning one can carry out the blasting with free angles of breakage.

Drilling Scatter

In general the scattering of drill holes as a quantitative factor is disregarded. It is included quite indefinitely in the technical margin together with the blastability of the rock, fragmentation and risk of non-ignition. For the discussion of blasting as a whole, it would be a great advantage if attention to drilling scatter, in common with the blastability of the rock,

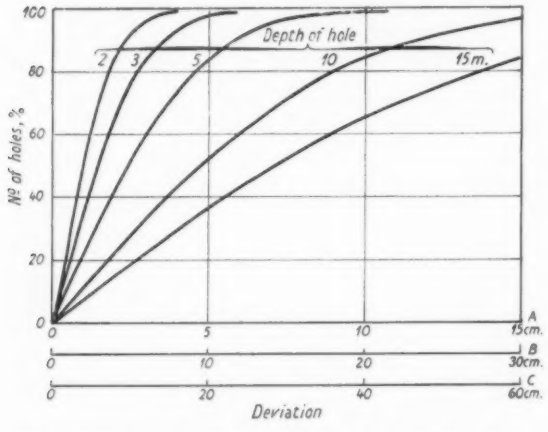

Fig. 3. Percentage number of holes of which the deviation at 2, 3, 5, 10 and 15 m. is less than that read on the abscissae; hand-held drilling machine, homogeneous rock; A *and* B *careful drilling with and without points of direction,* C *normal drilling of horizontal holes*

could be included in the calculation; for cut-blasting, this is essential.

Just as the drilling pattern is to be drawn up with the bottom of the holes as the point of departure, the scatter should also be studied there. Faults in the formation of the front-end of the drill holes (collaring), alignment and deviation through crevices and unevenness in the rock occur. The first-mentioned are by no means unimportant but can be eliminated with improved arrangements for marking the holes, and will not be further dealt with. The faults which most assert themselves at the bottom of the round are those in the alignment of the drill holes—contrary to faults in collaring they increase with the depth of the hole. They can be assumed to follow a normal distribution. With this assumption as a basis, graphs can be given (Fig. 3) for various types of drilling with hand-held machines.

It is proposed that drilling scatter be given as the deviation, expressed in centimetres or as a percentage (1 cm. per m.=1 per cent.), for the 84 per cent. point in the curves. This means that if five-sixths of all drilled holes have a lesser deviation than, for example, 1 cm. per m., the scattering of the drill holes is 1 per cent. It can also generally be said that the scatter is of the size 0·01 *Hm.* when *H* indicates the depth of

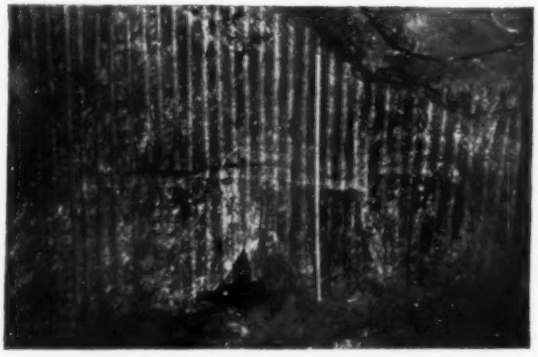

Fig. 4. Example of drilling scatter with hand-held drilling machine, using points of direction; centre distance between holes 5 cm., thickness of wall between holes 2 cm.

the hole. The curves in Fig. 3, which give scatters for 2, 3, 5, 10 and 15 m. hole depths, represent, according to this definition, a deviation of 1 per cent. when reading abscissa *A*. The corresponding values for *B* and *C* are 2 and 4 per cent. respectively.

The scatter of 1 per cent. presupposes that the drilling direction is checked with points of direction. Investigations in different rocks and under different conditions have shown that this precision can be achieved (Fig. 4). The values for *A*-*C* concern hand-held drilling machines, when drilling with a stationary frame deviations half as big as for *A* ought to be aimed at.

When drilling with stationary frames, which will be used more and more, not least because of the demands for greater precision, it is hoped to reach a value of scatter of about 0·5 per cent. It should, however, be pointed out that the maintenance of such high drilling precision will probably be achieved only after extensive investigations and new constructions.

The question of collaring, the elimination of drill swaying when using long rods and of drill guiding immediately behind the bit are the most important unsolved problems. It is suggested that it should be possible to solve the first-mentioned with the help of large collaring drills, the second with the right choice of feeding pressure in relation to the stiffness of the rod, possibly also by a guide which can accompany the drill into the hole. Guidance of the bit is intended to prevent deviations in the rock on account of crevices, etc. The importance of this problem increases with deeper drill holes as such deviations can be cumulative and will soon dominate the picture of the scattering.

Different Types of Cut

Fan. The fan cut can be taken as an example of a complete realisation of the relieving principle. In view of what has been previously mentioned, the uncertainty regarding the angle of breakage at the bottom is eliminated: a rectangle can be expected. With a knowledge of the burden and the width of the tunnel the construction of a breakage pattern for the cut is reduced to a purely geometrical problem (top of Fig. 5). On the other hand, we must not ignore the fact that the problem is three dimensional, so that we must have regard to the break conditions also in a surface perpendicular to the drill-holes at the bottom of the break and there apply the rectangular principle laterally (bottom of Fig. 5). It is only then that the

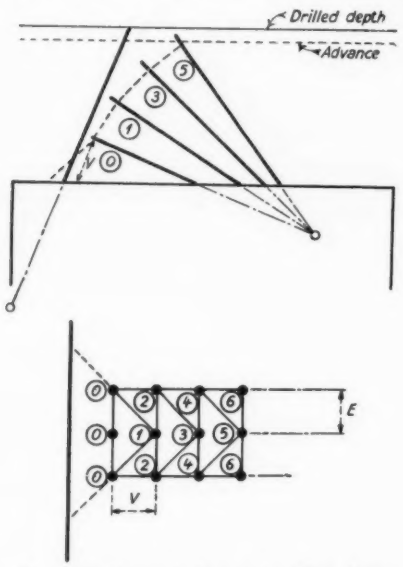

Fig. 5. Construction of fan cut. The figures give sequence of ignition, V *burden,* E *distance between holes*

consequences of placing the holes and sequence of ignition become evident. The distance between the holes E and the burden V is chosen with regard to the fact that they are mutually connected; in the case shown in the figure $E=V$. This should be taken into account when the number of holes has to be increased, which is sometimes necessary. The ignition pattern calls for special attention. A rearrangement of the sequence of ignition in a drilling pattern already given

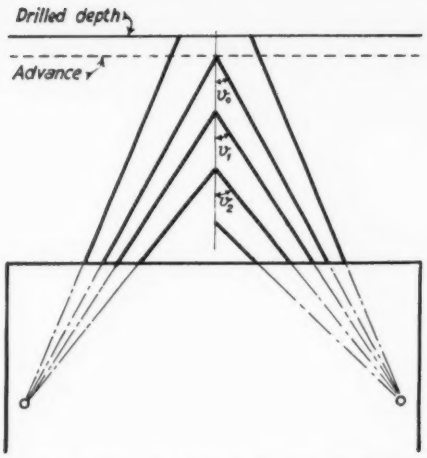

Fig. 6. Theoretical plan of plough or vee cut

can lead to an improvement in the final result. If so, this expedient should of course be chosen in preference to increasing the number of holes and the size of the charge. Fig. 5 illustrates the situation if we compare the indicated sequence of ignition with one in which the holes are ignited in threes. In such a case, the law of probability suggests that in two cases out of three one of the outer holes will detonate before the middle one. In these cases a considerably larger charge is required for breakage as there is not a free burden for the side holes. In addition, the surrounding rock is exposed to severe strain as a result of fixation, with a risk of tearing neighbouring holes and initiating cracks, which may have a bad effect on the breakage.

Plough (or Vee). There is a strange contrast between theory and practice as regards the plough cut. The maximum rate of advance here is about 45 per cent. of the width of the tunnel, and is therefore geometrically determined as in the fan cut (Fig. 6). This implies that the acute angle ($2v$) at the bottom is larger than, or equal to, 58° (cot $v=1{\cdot}8$). In principle,

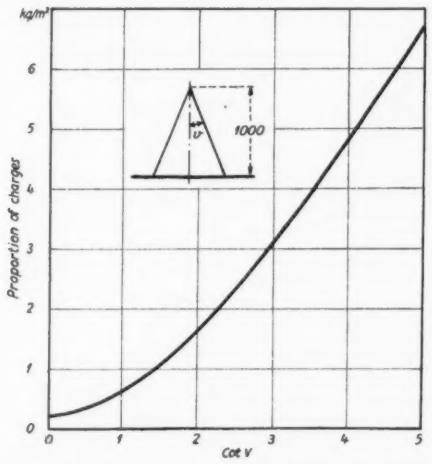

Fig. 7. Relationship between charge and acute angle for a simple vee cut with a depth of 1 m. The holes are drilled to meet. Instantaneous ignition (qualitative curve)

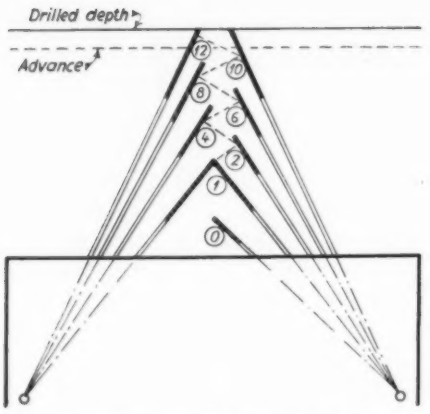

Fig. 8. Construction of drilling pattern for a vee cut. The figures give sequence of ignition

however, there is no such limit in the advance but there is a connection (Fig. 7) between weight of charge and cot v. Even at the value cot $v=2$ we have for wide tunnels an advance that is greater than is reached at present even with a moderate number of holes (12) and charge (0·3 kg. per m.). The curve in Fig. 7 applies, however, if the drilling has been carried out so that the holes meet in pairs at the apex, and if all holes belonging to the angle of breakage in question are ignited with a sufficiently small distribution of the timing.

How does this work in practice? A comparison with the distribution curves for drilling scatter (Fig. 3) shows that with the deviation one has reason to expect (scale C) the conditions cannot be fulfilled. The alignment faults are of the order of magnitude ± 4 per cent., which means that the holes at a depth of 5 m., for example, meet the centre line with deviations of ± 50 cm. One cannot then reckon on a flash-over from one hole to the other. In the way ignition is usually arranged, ignition scatter is so great that one can only count on co-operation between those holes which ignite by flash-over. Thus what really happens in practice is that most of the holes farther in the vee cut break out in succession without co-operation.

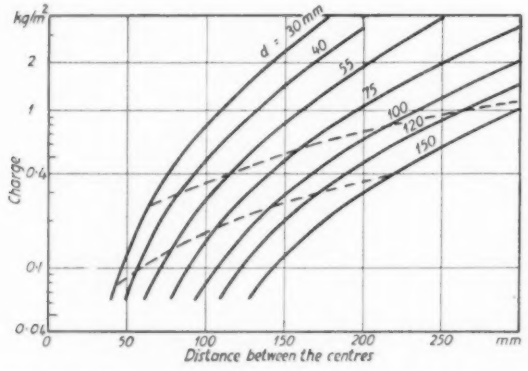

Fig. 9. Relationship between quantity of charge and distance between holes when blasting towards empty drill holes with dimensions 30-150 mm.—corresponds to the dotted lines in Fig. 10

In contrast to the actual basic principle for the vee cut the individual hole will then loosen the rock in front in keeping with the laws of free breakage. It is then consistent to revise the drilling pattern so as to begin from this and apply an ignition pattern which really gives free breakage (Fig. 8). A secondary condition which must be considered is that flash-over in this case must be prevented both between opposite holes and between contiguous ones. It implies that the drill holes, where they are fully charged, must not be allowed to be closer than 20 cm.

Cylinder. Entirely different aspects are given prominence in a cut with a parallel arrangement of holes, or cylinder cut. The calculation of the charge must in this case be placed on a wider basis so as to include conditions for acute angles of breakage close to empty holes. The connection which applies between charge quantity l, diameter of empty hole d and centre distance between holes a is covered by

$$l = 1{\cdot}6 \times 10^{-3}\,(a/d)^{3/2}\,(a - d/2)$$

and is graphically reproduced in Fig. 9. The formula

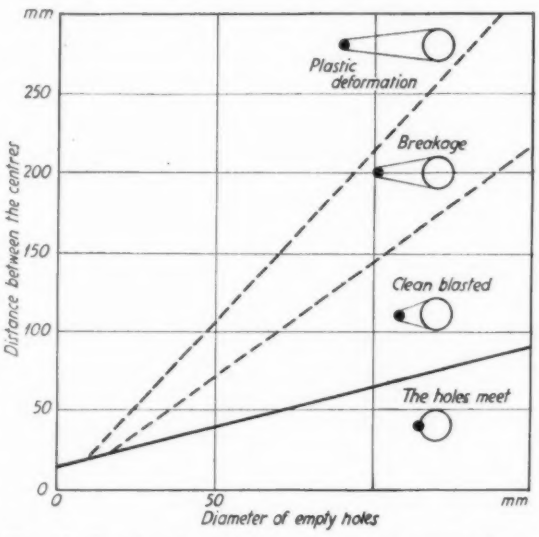

Fig. 10. Result when blasting towards empty hole at different distances and dimensions of the empty hole

indicated has first been determined empirically on a model scale, and has subsequently been adjusted in full-scale blasting to apply to rock.

It is remarkable, especially for small diameters of empty holes, how much the charge must be increased with increasing distance between the centres of the holes. For $d=30$ mm. a charge of 1·0 kg. per m. is required at a centre distance of 11 cm., but less than half the charge is needed at a distance of 8 cm. It is important to note this fact, not so much in view of the saving that can be made in charging, as on account of the great disadvantage in employing powerful charges in holes subject to fixation. The rock in the immediate neighbourhood of the hole is exposed to violent strain, which causes risk of tearing, gives less favourable possibilities for breakage in neighbouring holes, and adds considerably to the risk of erroneous sequence of ignition from flash-over.

Even if the condition for charging according to Fig. 9 has been fulfilled the result of a blast can differ

entirely owing to the relation between the centre distance and the diameter of the empty hole. For large values of this ratio a proper break cannot take place. The rock between the two holes is shorn off or deformed plastically so that the empty hole is more or less filled with solid rock after the blast. If the holes are placed closer together fragmentation of the blasted rock can be obtained. If the firing is done from without and inwards it may even be possible to throw the blasted rock out of the holes. This can be entirely cleared for a distance of several metres (Fig. 10). With strong supercharges, however, plastic deformation with the rock compressed in the hole can take place even in those areas which are marked "breakage" and "clean blasted."

The important question of the most suitable distances between the holes and how they should be placed has thus been put on a basis which makes it possible to deal with the problem by calculation. An operational analysis can be made of different means of attack which can be employed against a tunnel front. Such an analysis must include data of drilling scatter from faults in alignment and from deviation due to unevenness in the rock. The deviation permissible for each hole in a drilling pattern is first established, and then how many and which of the holes must lie within the limits indicated, and how, from a statistical aspect, conditions vary at different depths of hole. The deviations, in this case, will set a definite limit for the possible advance.

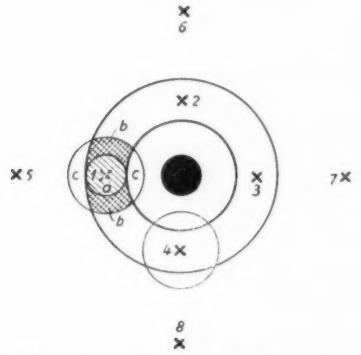

Fig. 11. Calculation of maximum advance when parallel-hole blasting for a cut according to Fig. 13b; diameters=35 mm., quantity of charge in the centre hole 0·6 kg./m., in holes 5—8 1·0 kg./m.

How this is calculated for an example with a conventional burn-cut of the Grönlund type (cp. Fig. 13) will now be shown. In Fig. 11 the charged centre hole and the centres of the nearest holes have been marked out and numbered from 1 to 8. If the centre of hole No. 1 falls outside the patched surface the distance to the charged central hole is either too large for a break to take place from there to No. 1, or else the hole is wrongly placed having regard to the effect of holes Nos. 2, 4 or 5. At a depth where two or more of holes 1—4 have been wrongly drilled in the manner indicated the cut can no longer operate. The statistical limitation (Fig. 12) of the advance in the calculated case depends on the scatter of the holes, which again is decided by the quality of the rock and the alignment faults. The significance of the calculated functional

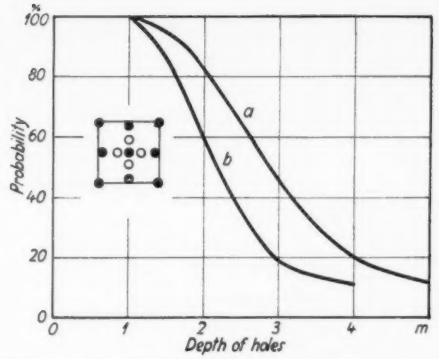

*Fig. 12. Probability, with respect to drilling scatter, of a successful cut at the bottom for parallel-hole blasting. Deviation through alignment faults 0·01*H. a *homogeneous rock,* b *deviation through unevenness in the rock 0·005*$H^{3/2}$

connections is that with a hole 2·0 m. deep in homogeneous rock it is possible to get full advance in a good 80 per cent. of all the cases; in 90 per cent. a greater advance than 1·75 m. is obtained, in 95 per cent. greater advance than 1·5 m., etc. On a probability summation we arrive at an average advance of 1·94 m. The corresponding figure in unhomogeneous rock is 1·83 m. For the average advance as a function of hole depth Table I can be given for both the calculated cases.

TABLE I

Depth of hole	Average advance			
	Homogeneous rock		Unhomogeneous rock	
m.	m.	col. (*b*) / col. (*a*)	m.	col. (*d*) / col. (*a*)
(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
1·0	1·0	1·0	1·0	1·0
2·0	1·94	0·97	1·83	0·92
3·0	2·58	0·86	2·20	0·73
4·0	2·89	0·72	2·34	0·59
5·0	3·04	0·61	2·44	0·49

In making these calculations the limitation of advance that must be expected to exist even when the placing of the holes is absolutely exact has not been taken into consideration. It is probable, however, that in many cases, at least in blastings that have hitherto been carried out, this limit is beyond that indicated by the relations in the table. This would seem to be a reasonable supposition if we compare the average advance values with practical experience with the

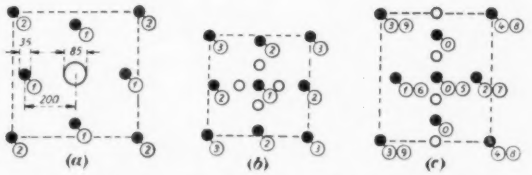

Fig. 13. Drilling patterns for some different burn cuts. a *Michigan type, average advance 3·0 m.;* b *Grönlund type, advance achieved, 3·2 m.;* c *de Jounge type with divided charge, advance achieved 3·9 m. The figures indicate sequence of blasting*

type of cut in question. The advance is generally given at about 2·0 m.

The supposition is directly confirmed by interesting tests by the Stockholm Harbour Board in which Grönlund, the engineer in charge of rock drilling, has proved that the cut in question can give an almost full advance in homogeneous rock at a depth of hole of 3·2 m. in several instances. The prerequisite for this result has been an extreme precision in the drilling with deviations which fall below even those already dealt with, of the order of magnitude of 0·01 *H*.

On the other hand, the blasting limit for the advance, if it can be indicated thus, may decide the method of attack when larger advances than those at present in use have to be considered, and in such cases the limitation can be overcome by short-delay blasting. Part-charges can be successively fired at intervals of some hundredths of a second, and thus secure co-operation with the escaping gases so that the hole can be blown much cleaner. Flash-over between the part-charges is prevented by sand plugs 0·06 m. long.

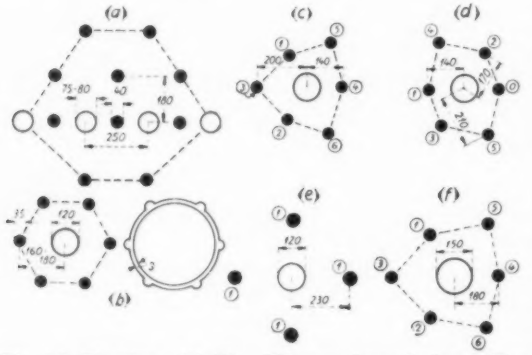

Fig. 14. Blasting with 75—150 mm. large holes. a *Slot cut with divided charge, permissible hole deviation for small holes ±4, ±5 cm.;* b *Instantaneous blasting with compression of the rock inside charged holes (to the right, the rock is compressed at the moment of blasting), permissible deviation ±1·5, ±6 cm.;* c *Three-section cut, permissible deviation ±3·5, ±5·0 cm.;* d *Blasting with double spiral, permissible deviation ±3·5 ±4·3, ±5·0 cm.;* e *Magnified Michigan cut, permissible deviation +5·0 cm.;* f *Three-section cut with 150 mm. large hole, permissible deviation of hole ±5·0, ±7·0 cm.; figures in circles indicate sequence of ignition*

L. de Jounge, in a paper of great merit, has examined the conditions for such successive short-delay blasting of some different types of burn-cuts, one of which is given in Fig. 13*c*, and in the course of this reached as great a depth as 3·9 m. in individual cases. De Jounge pointed out that ridges were left in front of the sand plugs and that the different charges should be placed so that they gradually remove these ridges.

It is evident from the calculations, however, that unless there is a fundamental improvement in the precision of drilling in current operations advances of 3 m. or more cannot be obtained for ordinary burn-cuts. For this a drilling pattern which allows greater tolerance in placing the holes is required. A moderate improvement may possibly be attained by rearranging some of the holes of the pattern. Another possibility is to double the cut; by increasing the number of holes the same effect, or part of it, can be obtained. It can, however, be seen in analysing the different means of attack that an increase in the dimensions of the holes gives quite a different result in attempts to increase the advance.

The blasting then takes place towards one or more empty large holes, when the conditions of Figs. 9 and 10 apply. With 75 mm. holes three or four are required for average advances above 4 m. For the slot cut, reproduced in Fig. 14*a*, the estimated average advance is 5·0 m. in a raise, if the large holes are assumed to deviate not more than half as much as the small holes. Such cuts have in tests by the Stockholm Harbour Board been blasted to a depth of over 7·5 m. in some cases. With the same type of cut and 55 mm. large holes an advance of 4·75 m. has been obtained in horizontal cuts.

As it is a question of parallel arrangement of the holes the data given do not presuppose that the tunnel area is a major one; they can be adopted even with an area of 0·5 sq. m. It will be seen from the above that data regarding occasional advances cannot be taken as characteristic of a certain cut. The decisive factor is the practical working average value and the upper limit of this, the advance average value calculated from the drilling analysis.

By increasing the diameter of the large holes the number can be reduced. From many aspects blasting with a single large hole is simplest, but then the hole must have a diameter of at least 110 mm. in order to give a possible average advance of 4·0—4·5 m. under given conditions of hole scatter. With increasing diameters of large holes the advance can be increased so that with a diameter of 150 mm. a calculated advance of about 6 m. can be obtained.

Different principles can be employed for the placing of holes around such a large hole. The advance figures mentioned have been calculated for a placing of holes (Fig. 14*c*) where the cut is made in three sections, the first consisting of holes 1, 2 and 3, where every hole is ignited separately, the second of holes 4 and 5 and the last of hole 6 in a cut towards holes 2 and 4. Another type (Fig. 14 *b*) is intended for instantaneous ignition of all six outer holes simultaneously. The rock is compressed at the detonation and is thrown out of the hole (Fig. 14*b* right). This cut implies a rock without large cracks and crevices, as the section for ejection is rather narrow.

It is rather attractive from certain aspects to place the holes in a spiral arrangement as it will then be possible to blast a larger opening with the same number of holes. The great weakness with such a cut is that if a single hole is wrongly placed it is not possible for the following holes to give a break. In order to give the spiral cut satisfactory statistics double security can be arranged (Fig. 14*d*), when the cut can be made in the one half even if the other has been wrongly drilled.

Blasting with a cut of the Michigan type can, of course, also be done with larger central holes than for the conventional one (Fig. 14*c*), which gives an advance increased in proportion to the linear degree of enlargement. Fig. 14*f* shows a three-sectional cut with a 150 mm. large hole.

It will be seen from the discussion that in order to

(Continued on page 28)

The Tubular Turbine

Between 1936 and 1951 Escher Wyss built 75 tubular turbines having an output of approximately 143,000 h.p. Whereas these tubular turbines, which are also referred to as submerged turbines, were still the subject of criticism during the first post-war years, the view is now becoming more and more accepted that this particular type has its justified field of application. The purpose of this article is to review the development of these turbines up to the present and examine future prospects.

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WITH the introduction of propeller turbines having fixed runner blades followed by turbines with adjustable runner blades, referred to as the Kaplan type after their inventor, a development in the field of water turbines was brought to a conclusion. Due to this advance it became possible on the one hand to reduce initial costs considerably by adopting higher speeds and thus physically smaller units, and on the other hand to ensure the most favourable efficiencies from the available quantity of water, thanks to the possibility of co-ordinated adjustment of the positions of guide vanes and runner blades.

Following the knowledge and experience gathered in aerodynamics it proved possible, especially with high-speed turbines, to increase the efficiency by adopting favourable blade profiles and by reducing flow losses in the inlet chamber and draught tube, to such an extent, indeed, that further major improvements will hardly prove feasible. An important factor during this development was the research carried out in connection with cavitation in high-speed machines. The knowledge hereby acquired now permits the adoption of axial-flow water turbines having adjustable blades for heads up to about 60 m., which has led to the supersession of high-speed Francis turbines such as were hitherto adopted for these conditions.

To reduce the dimensions of the buildings, the vertical arrangement of the shaft is usually preferred, whereby the drawback is accepted of the turbines being accessible only after removal of the generators situated above, or at least the generator rotors. For medium and large installations the two-bearing design has been adopted to an increasing extent, in which the generator rotor is overhung on the upper shaft end and the stator protected by a weatherproof hood; in this manner a machine house proper can be dispensed with. A further reduction in the overall dimensions of the building has been aimed at by adopting an arrangement with inclined guide vanes. In this way the dimensions of the inlet spirals can be reduced in plan and the required hydraulic cross sections obtained by additional height, to such an extent that it becomes possible to install a machine in a suitably designed spillway pier.

The results obtained with the design employing a spiral casing, axial runner wheel and elbow-shaped draught tube, however, are not always satisfactory, as the flow from inlet to runner wheel is still relatively long, and the admission to the runner wheel and subsequent discharge in an elbow-shaped draught tube involve repeated deflection of the flow.

More favourable flow conditions without important deflection losses between inlet and outlet are obtainable with axial turbines having horizontal or inclined shafts, but if one takes into account the additional floor area required and the need to serve this area by the power-house crane, an increase in the cost of the civil-engineering work is involved, which proves uneconomical. At best the latter only remains within admissible limits, as compared with the expenditure for the vertical arrangement, where small or medium-sized installations are concerned.

An arrangement in which a horizontal axial-flow turbine drives a vertical generator through a bevel gear installed inside the guide-wheel hub proves more favourable in meeting the requirements of good water flow and economical expenditure on the building work. A prerequisite for the adoption of this design is reliable sealing of the gear, which operates in an oil bath. If this can be satisfactorily fulfilled, then the generator can also be installed within the guide wheel hub as in the case of the Rostin plant (Fig. 1). It is here that

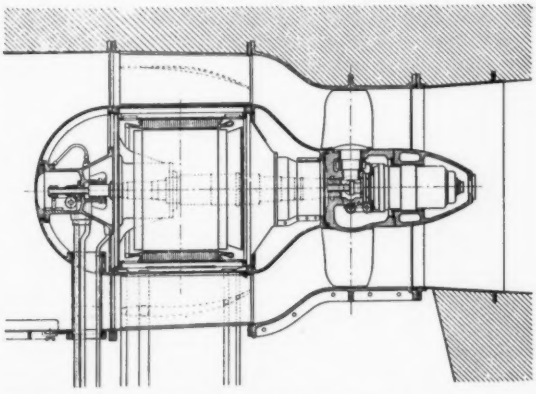


Fig. 1. First axial-flow turbine built by the Ravensburg works of Escher Wyss, with generator arranged in the guide wheel boss, at Rostin power station, Pomerania. Supply of cooling air and discharge of possible leakage water through the hollow wicket gates. Average head 3·75 m., quantity of water 6·3 cu. m. per sec., output 265 h.p.

the development of the axial-flow tubular turbine, also known as an "Arno Fischer turbine," commences.

The two turbines of the Rostin plant (Pomerania) built by the Escher Wyss works at Ravensburg in close co-operation with Arno Fischer have been in operation since 1936. Each deals with 6·3 cu. m. per sec. under an average head of 3·75 m., which corresponds to a unit output of 265 h.p. The generator arranged inside the guide-wheel hub and built by Sachsenwerk receives cooling air through the hollow guide vanes, through which condensed water and possible leakage water are also led away. At the runner end the guide-wheel hub is sealed against the rotating shaft by a stuffing box employing rubber lips. For shutting off the turbine there is a butterfly valve on the intake side and a stoplog on the discharge side (Fig. 2). The turbine sets have no power house of their own but are installed actually within the weir. Apart from the savings in the civil-engineering work, installations of this kind are well suited to the surrounding scenery. Impounding of the water upstream is effected by segment-type sluices in the weir. When there is a surplus flow of water, the whole plant is covered and thus becomes a so-called submerged power station.

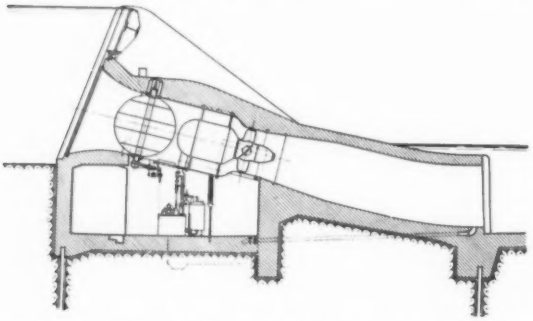


Fig. 2. Submerged power plant at Rostin with tubular turbine (see Fig. 1). Note that there is no power house, the turbine sets being built immediately in the weir, giving low building costs and unobtrusive arrangement of the plant

The experience gathered with this plant shows that in principle it is possible, at least for small outputs, to arrange the generator inside the guide-wheel hub, provided the external dimensions have not been chosen too small and the profiles of the guide vanes are dimensioned generously enough to allow of sufficient air cooling in the generator.

In later installations, particularly for larger outputs, the arrangement of the generator and the guide-wheel hub was dispensed with, and at the suggestion of Arno Fischer the magnet ring of the generator designed immediately as an external ring for the turbine runner wheel. In this way the generator again becomes easily

Fig. 3. Machine room of the submersible power station at Saalach, with new design of the tubular turbines as seen in Fig. 4

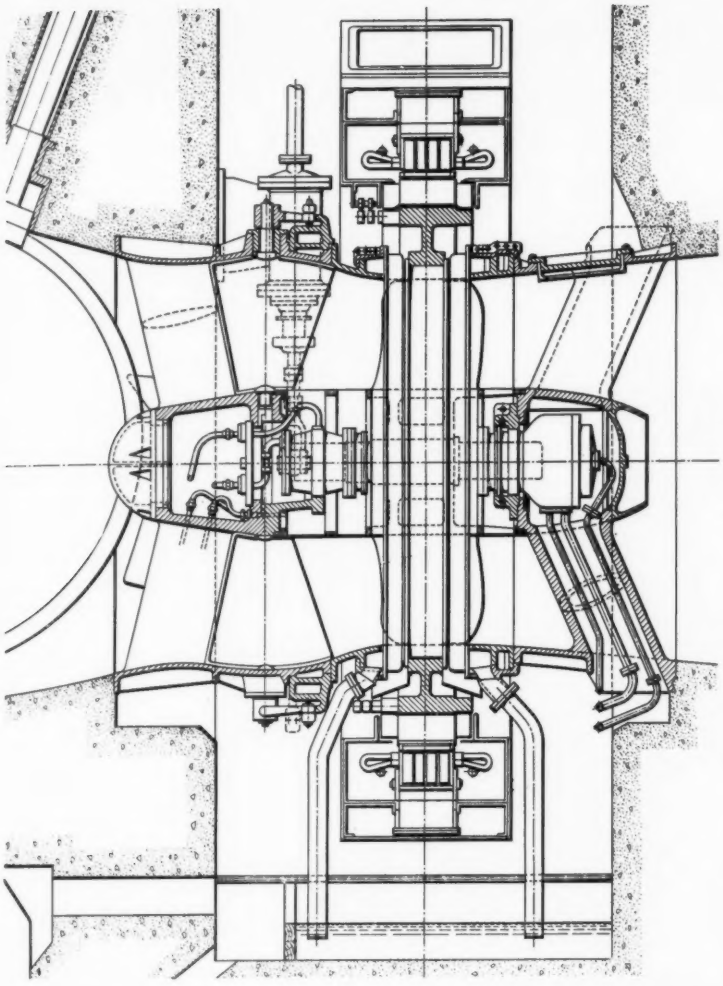


Fig. 4. New design of Escher Wyss tubular turbine. Note external rim of turbine runner designed as magnet ring of generator; favourable shaping for flow round guide-wheel boss; runner made in one piece of cast steel, diameter 1·95 m., blades cast on boss and external rim, magnet ring shrunk on; regulation simply by adjusting the guide vanes

accessible. With the larger magnet-ring diameter it is easier to accommodate the required flywheel effect for proper regulation of larger units. At the same time the guide-wheel hub can be more favourably designed for the flow.

In developing the design, the rather difficult problem arose of sealing the external rim of the runner wheel, rotating at more than 20 m. per sec., and the stationary tubular parts in such a manner that no water could come in contact with the windings of the generator. The methods of shaft sealing so far adopted for small circumferential velocities did not offer any sufficient basis for solving this problem. Escher Wyss did not hesitate to undertake the trouble and expense involved in carrying out the necessary pioneer work step by step, and the required data were obtained on the testbed about wear and friction in the seals, leakage losses, lubrication and cooling, and friction of the rotating rim.

Opportunity for the first practical execution of a tubular turbine with external rim was presented when a development was being planned on the Iller river under the direction of the Bavarian Ministry of State. Between 1937 and 1951 Escher Wyss thus installed, under contracts from the Lech Electricity Works, Augsburg, four tubular turbines in four separate stages, each of about 9 m. head. The maximum flow is 25 cu. m. per sec. per turbine. Shortly after the first stage on the Iller river had been put into service an order was received from the Bavarian Water Power Company, in Munich, for 54 further turbines intended for harnessing the Lech river, in which a series of six turbines each were installed in a number of stages of about 8·5 m. head, the quantity of water being 20 cu. m. per sec. per unit.

Three further tubular turbines delivered by Escher Wyss have been in operation since 1951 at the Saalach power station (Fig. 3) belonging to the Municipality of Salzburg. Under a head of 8·5 m. two of these turbines deal with a full-load water quantity of 20 cu. m. per sec. and a further turbine with 15 cu. m. per sec. The design of such a tubular turbine is illustrated, in principle, in Fig. 4. The runner wheel is supported on the headrace and tailrace sides by means of radially arranged stay vanes. The oil and leakage-water pipes leading to bearings and stuffing boxes are accommodated in the hub of the stay-vane ring on the discharge side. A segment-type thrust bearing is arranged in the boss of the radially arranged stay vanes on the downstream side. Since a negative axial thrust can occur when shutting down, the thrust bearing is designed to deal with this. An adjustable axial guide wheel is employed for regulation; its wicket gates can be moved by links and an operating ring from servo-motors acting under oil pressure according to the prevailing change in load. With the exception of one tubular turbine that was installed in the Iller river in 1951, all other turbines of this kind have so far been equipped with runners made in one piece of cast steel, the blades of which are rigidly cast on to the boss and external rim. The outer diameter of the runner blades is 1·95 and 2·15 m. The external rim serves as a support for the shrunk-on magnet-wheel ring.

The turbine bearings, which are in contact with the operating water on the outside whereas they are under oil pressure on the inside, are sealed by stuffing boxes developed for the purpose. These boxes have a lip of special rubber which seals against the external water

pressure, and two of these members seal against the oil pressure in the bearing. Between the members there are two annular chambers from which the leakage water or leakage oil can be led away through pipes. Thanks to the reliable shaft sealing, satisfactory lubrication of the bearing by means of oil under pressure is rendered possible.

Sealing between the runner rim rotating in water and the stationary turbine casing is likewise effected by the so-called lip seals. When the turbine is empty these lips can be easily fitted or adjusted from the inside and are held in place by rings. As a protection against wear, the rim of the runner is protected on both sides with cover rings of wear-resisting material. The lips seal so tightly that each turbine has a leakage of only 2 to 4 litres of water per second, which can readily be dealt with by the annular collecting tray on the turbine casing, from which it is led, without disturbance to the generator, into the leakage-water sump of the plant. The collecting trays in their turn are sealed by further lips against the spray rings fitted to the magnet ring. In this manner reliable protection of the generator against leakage and spray water is brought about.

To facilitate erection, a design with horizontal shaft was adopted for the Lech turbines (Fig. 5), in contradistinction to the stages of the Iller river and to the Saalach power station where the shafts have an inclination of 1 : 2 and 1 : 2·5 (Fig. 6). Nevertheless, the inclined sets have not given rise to any difficulties, and seeing that objections on the ground of more difficult erection are not borne out in practice, preference should be given to the inclined design in view of the still better inlet passage, the shorter inlet distance, and the easier location of an access passage under the machine with the same or even smaller excavation depth.

Each turbine is provided on the headrace side with a butterfly valve operated by oil under pressure. On the tailrace side a hand-operated sluice gate can be inserted if this proves necessary for overhauling the turbine. Several pumps with electric motor drive are available in each installation for dealing with leakage water coming from the collecting trays of other parts of the plant. They discharge this water from the sump situated at the lowest point and hereafter into the tailrace. If the supply of current should fail, the discharge is dealt with by an emergency pump driven by an internal-combustion engine. Moreover, the sump pits are so generously dimensioned that they can take up the small quantities of leakage water for several hours before the water needs to be pumped away.

In the case of these installations the power house is designed as a weir construction and provided with a flap weir in such a manner that a water cover of several metres exists at this point. During flood a large part of the water can be passed over the weir by lowering these flaps and, by suitable shaping of the weir itself, employed to increase the head by means of suction action. Such an increase in head that can be brought about in a submerged power station hardly proves possible to the same extent in power stations of other designs.

Furthermore, as a consequence of the impounding action, the screen on the inlet side is arranged so low that fouling from flotsam on the surface of the water is largely avoided, and it proves sufficient simply to discharge from time to time the foreign matter collecting on top of the weir. However, for reasons of safety, a track is still laid along the weir so that a machine for cleaning the screens can be brought into action if necessary. A machine of this kind has so far proved desirable only in the case of the uppermost stage of a group of such power stations.

Scour sluices serve for discharging the foreign matter collecting on the river bed, and in the case of the installations in the Iller river all these openings are situated in the weir construction on one side of the river bed and the turbines on the other side. For the stages in the Lech river two turbines and one scour sluice are arranged alternately over the whole width of the river. In the case of the Saalach power station there are four scour sluices with one of the three turbines installed between each. The space in the weir above the scour sluice serves as a store and erection bay for turbines and generators.

Shrinking of the rotating magnet wheels on to the turbine runners was effected in the works of the electrical suppliers, namely Messrs. A.E.G., Brown, Boveri & Co., Sachsenwerke and Siemens-Schuckert. With the aid of careful elongation measurements the changes in shape and stresses occurring during this work were carefully determined. In this way the neces-

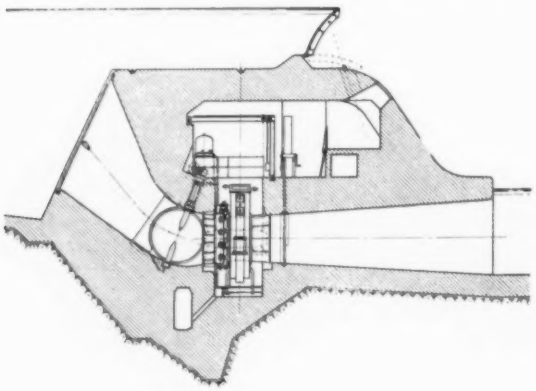


Fig. 5. Submersible-weir power plant with tubular turbine arranged horizontally to facilitate erection

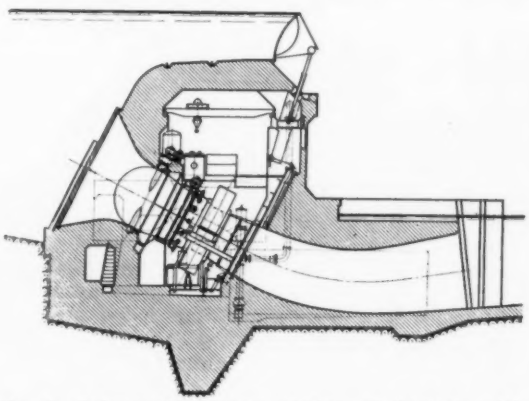


Fig. 6. Submersible power station at Saalach with inclined tubular turbine, affording a short inlet and better guiding of the incoming water

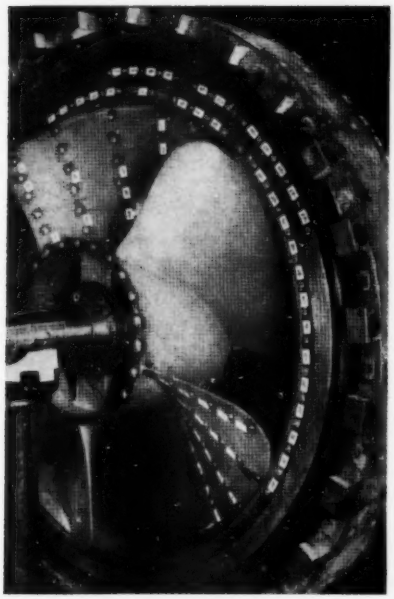


Fig. 7. Runner-wheel assembly with strain gauges affixed thereto. Readings taken before and after shrinking-on of the magnet wheels provide the basis for strength calculations

sary basis for calculating the strength of such sets became available (Fig. 7).

The planning of a number of identical power stations with identical turbines on the Iller and Lech rivers (Fig. 8) permitted manufacture to a considerable extent on quantity-production lines, and a special suspension rig was employed which led to substantial savings during erection (Fig. 9).

The hydraulic questions were settled in all details on the basis of exhaustive model tests. Exact comparative measurements on a separate testbed have shown that the additional losses from friction and leakage water on the external rim of these turbines is readily compensated by the smaller flow losses in the short nozzle-shaped inlet and the almost straight draught tube in place of an elbow-shaped one. These hydraulic model tests were carried out on a runner of 300 mm. diameter under a head of 4·70 m.

In autumn 1948 an opportunity presented itself to carry out full-scale tests on machine No. 6 of the Lech stage, belonging to the Bavarian Hydro-Electric Co. Ltd., Munich. Ten measurements were made for determining the efficiency at different admissions. The acceptance trials took place under the direction of Prof. Dubs, Zurich, as hydraulic expert, and Dr. Osanna, Munich, as electrical expert.

To ensure proper measurement of the water it was necessary to provide a measuring channel of about 37 m. length connected to the draught-tube outlet. The water measurements themselves were effected at

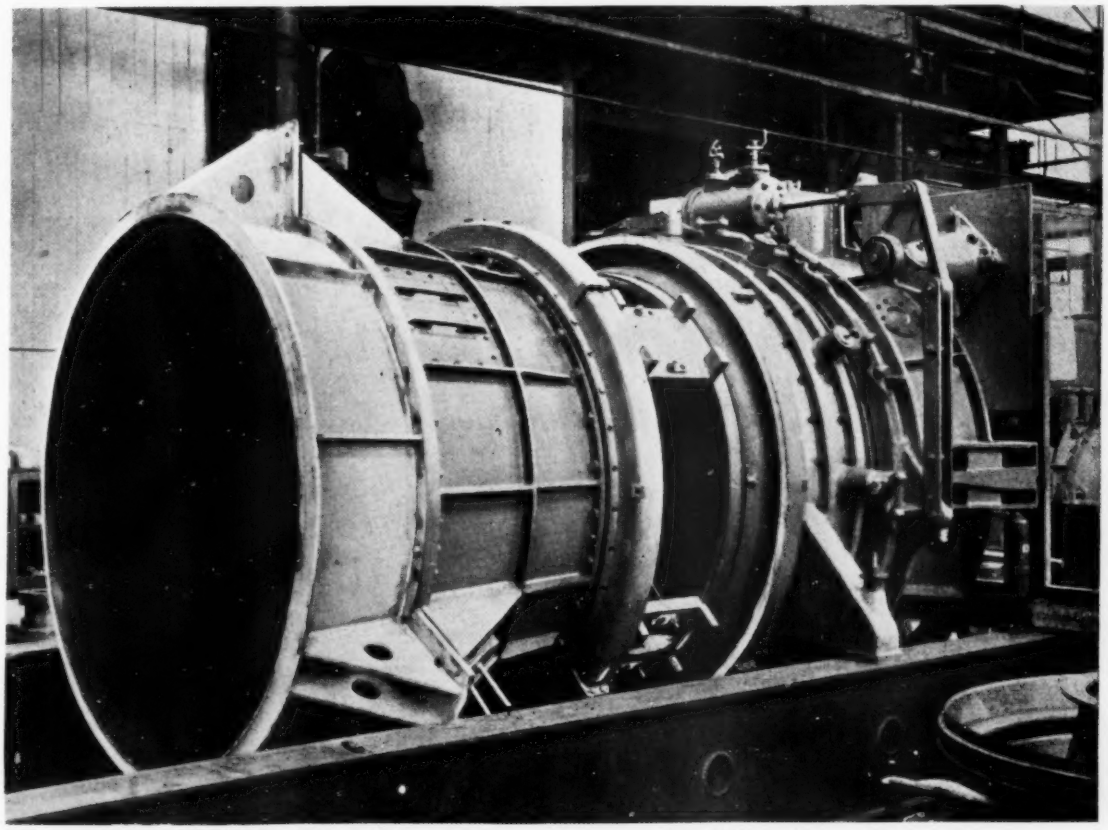


Fig. 8. An Escher Wyss tubular turbine under construction. The equipment of a number of power stations with identical machine sets has led to economies in manufacture

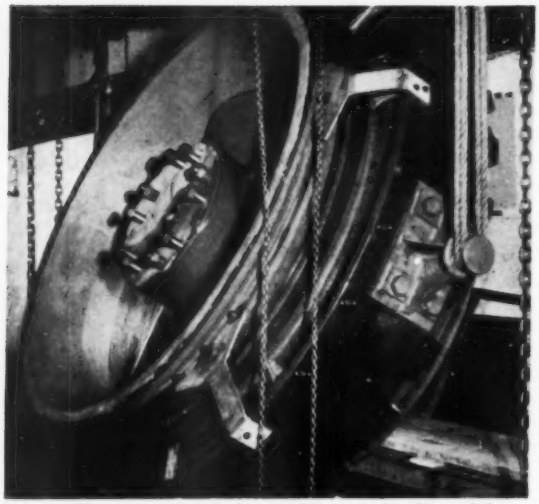


Fig. 9. Erection of tubular turbines is facilitated by a special lifting rig

the end of the measuring channel within a submerged cross section measuring 1,965 mm. high and 4,427 mm. wide. The velocity distribution was measured simultaneously with six Ott current meters in ten vertical positions. When subsequently making the calculations a very uniform velocity distribution was determined. This may mainly be due to the wooden members inserted in the measuring channel at a distance of about 12 m. before the measuring cross-section, whereby the irregularities coming from the draught-tube discharge were equalised.

The useful head is obtained from the difference between the energy lines before and after the turbine. In the present case the range of the turbine commences after the butterfly valve and terminates in the tailrace cross section, where the water levels in the tailrace were measured. For determining the useful head it was, therefore, necessary to take into account the losses in the screen, supply pipe and butterfly valve, and to obtain these pressure losses, six circumferential pressure-measuring points were set up around a cross section immediately after the butterfly valve, i.e. where the water enters the turbine range. To obtain as reliable a figure as possible for the useful head concerned, the calculation of a weighted average figure was taken as a basis by Prof. Dubs.

During the acceptance trials the output of the turbine was transmitted through its three-phase a.c. generator to a water resistance built for the purpose. This water resistance functioned most satisfactorily during the tests and the load remained very stable. The mechanical and electrical losses in the generator were determined on site by separate trials.

From the measured and calculated figures the data given in Table I were obtained. As may be seen from this table, operation took place in the main at each of the adjusted guide-wheel openings at normal, reduced, and increased speeds, in order to determine the influence of speed at the head prevailing during the testing period; or, what is theoretically the same, in order to find out for a given speed (in the present

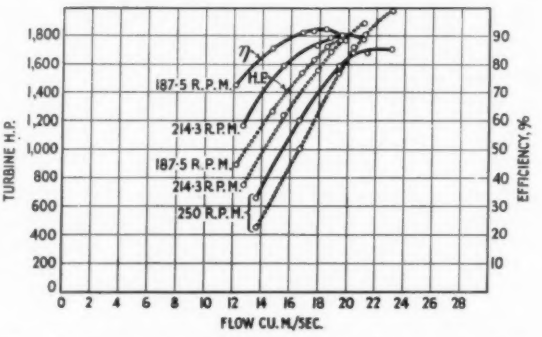


Fig. 10. Test curves of output and efficiency against flow. Conversion of the figures obtained during the acceptance tests to the guaranteed useful head resulted in a peak efficiency of 92·4 per cent. at the speed recommended by Escher Wyss, and efficiencies over the whole range higher than the guaranteed figures

TABLE I

Test No.	a_o	n	H_n	Q	P_G	η_G	P_T	η_T
1	80	214·4	6·665	20·64	1186·33	96·31	1613	87·9
2	70	214·2	6·793	19·12	1134·95	96·26	1544	89·1
3	60	214·3	6·921	17·48	1016·32	96·06	1382	85·3
4	50	214·3	7·126	15·39	836·38	95·77	1138	77·9
5	40	214·0	7·273	12·61	513·07	93·97	699	57·2
7	66	213·0	6·846	18·23	1086·23	96·20	1479	88·7
10	66	213·0	7·042	18·69	1142·40	96·28	1555	88·5
11	80	185·0	6·780	19·32	1143·88	96·15	1556	89·0
12	70	185·0	6·935	18·04	1115·68	96·07	1518	90·8
13	60	184·5	7·020	16·47	1028·54	95·95	1400	90·7
14	50	185·5	7·146	14·59	870·29	95·51	1183	85·1
15	40	184·0	7·281	12·14	629·74	94·58	856	72·5
16	65	185·0	6·992	17·33	1087·95	96·04	1480	91·5
18	80	237·0	6·621	21·86	1213·70	96·20	1650	85·5
19	70	236·0	6·712	20·30	1129·93	96·12	1536	84·6
20	60	237·0	6·827	18·45	987·86	95·93	1345	80·0
21	50	237·0	6·966	16·05	693·30	94·94	943	63·3
22	40	237·0	7·135	13·21	356·17	91·44	485	38·5

a_o Guide-wheel opening in degrees
n Turbine speed in r.p.m.
H_n Useful head in metres
Q Quantity of water in cu. m. per sec.
P_G Generator output in kW
η_G Generator efficiency in %
P_T Turbine output in h.p.
η_T Turbine efficiency in %

case 214·3 r.p.m. corresponding to 50 cycles with 28 poles) the influence of a head that is subjected to seasonal changes on the efficiency.

A conversion of the test results to the guaranteed useful head of 7·5 m. may be seen from Fig. 10. At a speed of 187·5 r.p.m., as proposed by Escher Wyss when the plant was projected, it follows that the turbine would attain a peak efficiency of 92·4 per cent. and that the unit would operate over the whole range of guarantees at considerably better efficiencies than with the speed of 214·3 r.p.m. as adopted for the actual execution, at which a peak efficiency of 90 per cent. is nevertheless also reached. As might be expected, the opposite is the case at 250 r.p.m.; for this speed a considerable loss in efficiency occurs.

In his summary Prof. Dubs writes the following:

"The measurements and their calculations show that the tubular turbine No. 6 of the Lech power station, stage 10, not only attains the guaranteed output under the specified data, but, in fact, exceeds these figures by 14 per cent. The same applies to the efficiencies, which especially under large loads, are very appreciably better than had been guaranteed. Consequently the turbine corresponds not only to the guarantees, but considerably exceeds them, which is all the more remarkable because the water velocities in the inlet are relatively much higher than is usually the case in such installations."

As may be seen from the foregoing, these tubular turbines of Escher Wyss make can certainly bear comparison, both as regards reliability and efficiency, with the designs of turbines hitherto known.

As already mentioned, the tubular turbines so far

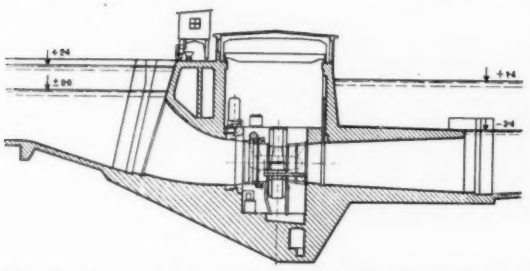


Fig. 11. Power plant with tubular turbine and open machine house. The compact dimensions of the tubular turbine permit small distances between the machines and savings in building expenditure as compared with power plants having axial turbines of normal design

built with the magnet wheel on the external rim have runners made in one piece with vanes rigidly cast in (except for one turbine in the Iller power station). However, the influence of the "pointed" efficiency curve is considerably reduced owing to the fact that the flow is distributed amongst a larger number of units than usual, each of which has to deal with a correspondingly smaller quantity of water (for example, six units in each stage of the Lech power station). This does not imply by any means that greater initial expenditure is always involved for the mechanical equipment and building work, because smaller units require less excavation work and have a shorter development length, especially of the draught tube.

The influence of the "pointed" character of the efficiency curve is further reduced if one employs the turbines, which are mostly intended for run-of-river power stations, by bringing them in successively at times when peak loads occur and by accepting a certain lowering of the impounded level in the range of best efficiency. The loss in head connected with lowering of the impounded level becomes of little importance when several stages of power stations are operated with a relatively high total head by the power supply company concerned, as is the case with the installations in the Iller and Lech rivers.

The equality, or even superiority, of the axial-flow tubular turbine, however, will only be placed on a wider basis when it also proves possible to build these turbines with adjustable runner blades, as in the case of Kaplan runners. In one stage of the Iller power station such a tubular turbine with double regulation was put into operation in 1951 as a test unit. During the course of the trials a few further changes in design were made. The operational experience thus gathered shows that no fundamental difficulties exist and that the special requirements involved by regulation of the runner wheel, such as supporting without vibration the relatively heavy magnet-wheel ring; dealing with expansion of the ring caused by heating and centrifugal force; reliable lubrication of the external bearings of the runner blades, etc., can all be solved in a reliable manner.

The installation of tubular turbines in so-called submerged power stations, or in other words weir power stations that can be flooded, is chiefly suitable for the ranges of heads from 6 to 15 metres. For lower heads uneconomically deep excavation is required, whereas for higher heads the increasingly exacting stresses on the runner become more and more difficult to deal with.

For the time being, importance is attached to a one-piece runner wheel and magnet-wheel ring, for reasons connected with strength, and their external diameters are limited to 4·5 m. owing to the requirements of the railway loading gauge, and in consequence the largest admissible external diameter of the runner blades has been found at present to be about 3·3 m. Nevertheless, in connection with the Ybbs-Persenbeug power stations on the Danube, which were originally intended to be operated as submerged stations, projects are available that have reached an advanced stage of design for tubular turbines, having runners made in several sections and with external blade diameters of 4·9 m. and unit outputs of 17,000 h.p.

The installation of tubular turbines, however, is not restricted to submerged stations. Thanks to their compact design a considerably smaller centre distance between machines can be adopted, and the excavation work can often be considerably reduced as compared with the usual axial turbines having concrete spirals. The foregoing, apart from other reasons, make the tubular turbine an interesting proposition also for power stations having normal machine houses (Fig. 11).

B.I.C.C. Bulletin. The Autumn 1954 issue of the Bulletin published by British Insulated Callender's Cables Limited contains several articles of hydro-electric interest, showing the part played by this firm in the construction of the Los Peares station, Spain, and Owen Falls, Uganda, as well as for the 42 ft. boring mill built by Craven Brothers (Manchester) Limited, for the John Inglis Co. Ltd., Toronto.

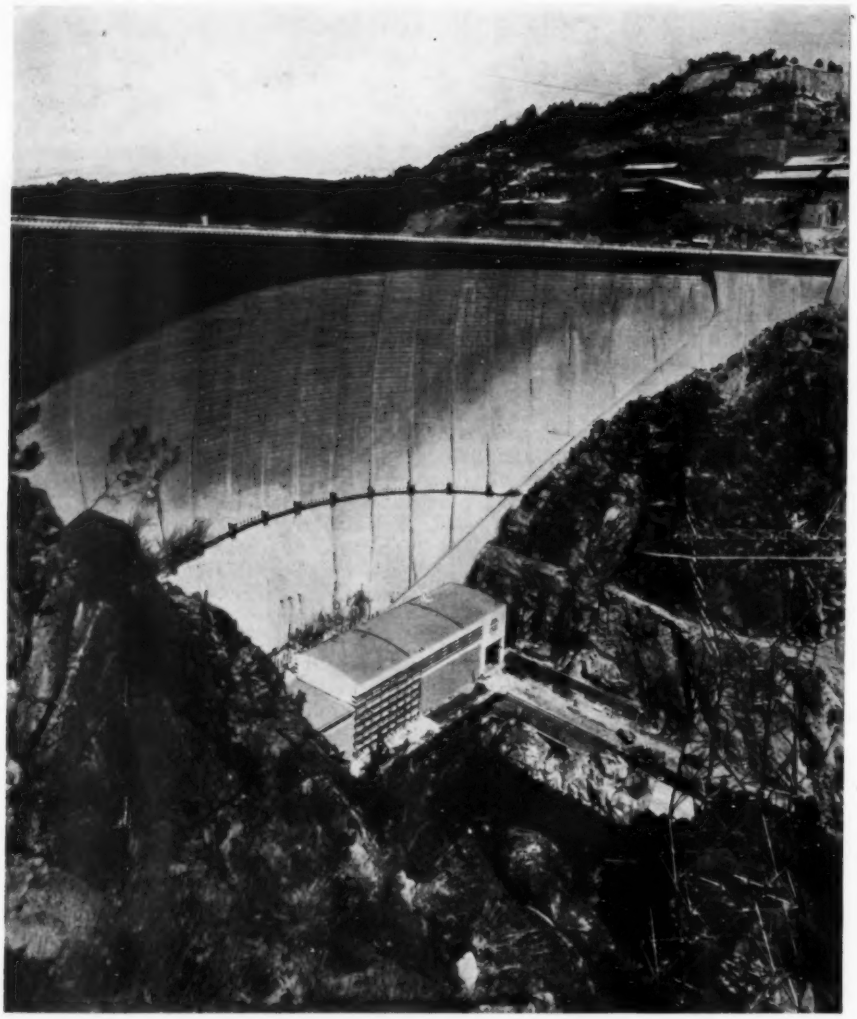


Fig. 1. Cabril dam and power station

Cabril Power Station

A short account is given of this station which was commissioned by Hidro-Electrica Do Zezere, Portugal.

THE Cabril power station, on the river Zezere, is the second of the large power schemes successfully promoted by the Hidro-Electrica do Zezere, the first station, Castelo do Bode, having been commissioned in 1951.* For both of these power stations the generating plant and switchgear have been supplied by two British companies, the English Electric Export and Trading Co. Ltd. and Metropolitan-Vickers Electrical Export Co. Ltd., acting together and known in Portugal as the "British Group." Since the first of the three 57,400 kVA sets at Castelo do Bode went into service in January 1951, the British plant has operated without any major trouble of any kind, and the station has generated a total of 900 million kWh

In April 1951 the Hidro-Electrica do Zezere instructed the British Group to proceed with the plant for the Cabril power station, comprising two 74,800 h.p. water turbines, generators, transformers and switchgear. It was required that the first set should

* "The Zezere Hydro-Electric Scheme." WATER POWER, May-June issue 1950, p. 93.

go into commission in May 1954, and early in May this set was duly turned round for drying out and commissioning tests, and on May 21st it was put into commercial service.

The Cabril dam and power station lie about 70 km. (44 miles) upstream of Castelo do Bode, so that water passing through the Cabril turbines can be stored in the Castelo do Bode reservoir and used again. With the additional dam and reservoir at Cabril the water level and storage facilities in both reservoirs can be conveniently regulated to afford a highly efficient use of the water available. This is particularly important on such a river as the Zezere, in which the flow is characterised by sudden flood conditions and long intervening dry periods.

The dam is a striking construction of the cupola arch type, with a double curvature, and is 132 metres (433 ft.) high. The reservoir extends some 53 km. (33 miles) upstream, and has a capacity of 700 million cu. metres (567,000 acre-ft.). Spillway capacity effected by two tunnels amounts to 4,000 cu. metres per second (140,000 cu. ft. per second).

The power station is arranged at the foot of the dam and the water is conveyed to the two turbines by means of steel penstocks, each 4 metres (13 ft.) diameter, and embedded in the base of the dam. Between the two penstocks there is a scour pipe 3·2 metres (10ft. 6 in.) diameter, leading to a disperser valve.

The step-up transformers and 165 kV switchgear are situated between the upstream wall of the power house and the dam, and the power is taken away by means of an overhead line to the Zezere substation (at Castelo do Bode), which forms part of the main 165 kV network for Portugal.

Station Arrangement

The machine hall, which has a single operating floor, contains the two main generating units with their governors and accessories. Both inlet valves are also arranged within this hall, so that they can be handled by the main service crane. The machine gauge panel, the valve control panel, the field suppression switch, and the controls for the various auxiliary services are all arranged on one board, which is inset into the upstream wall of the machine hall.

Also housed in an annexe to the hall is a 1,125 kVA auxiliary set, fed from a tapping off the main penstocks. The control room is arranged above this

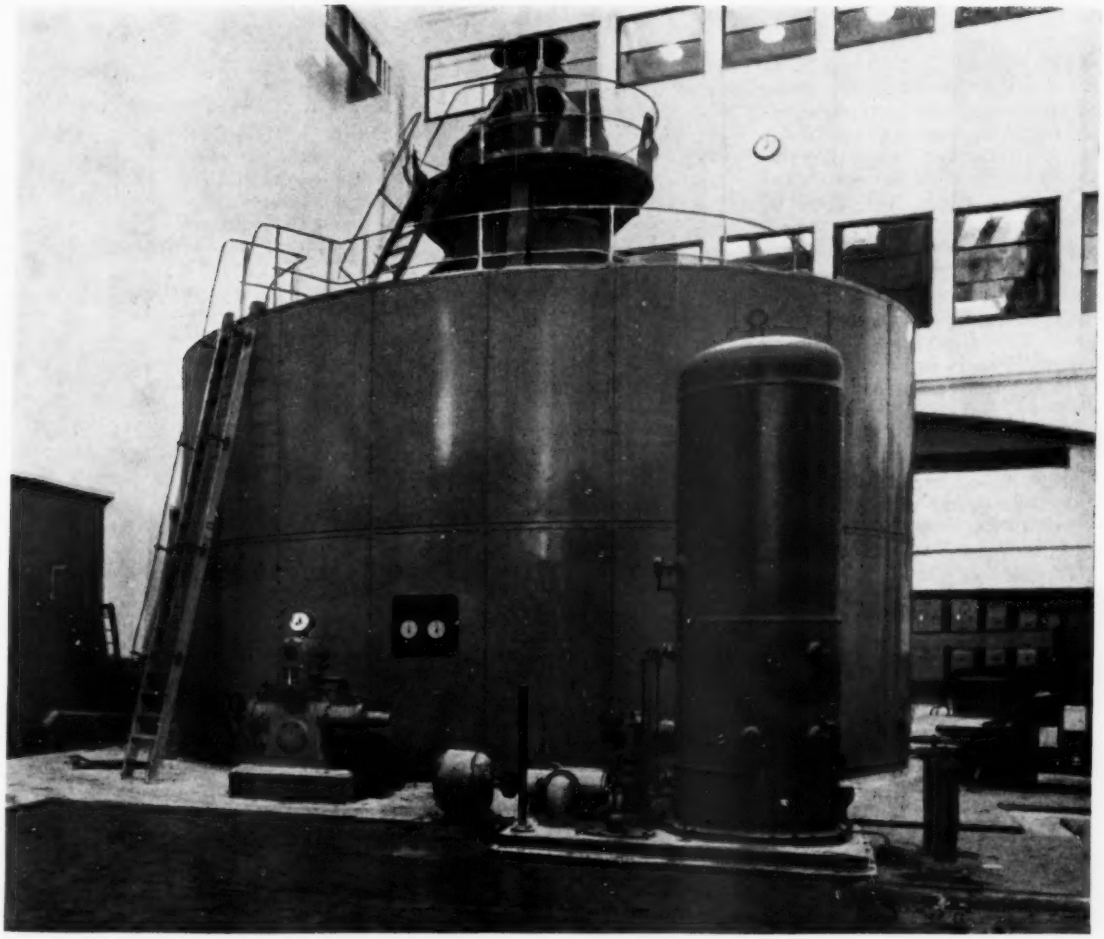


Fig. 2. 60 MVA generator and governor gear in course of erection

annexe and overlooks the machine room. The generator terminals are connected to the step-up transformers in the upstream substation by means of 15 kV bare copper busbars.

The two main turbines are of the vertical reaction type and run at 214 r.p.m. They are each designed for an output of 66,000 h.p. at the average head of 108 metres (355 ft.), but give 74,800 h.p. at the maximum head of 121 metres (397 ft.).

The turbines are very similar in size and construction to those at Castelo do Bode. In repeating the general design, however, special allowance had to be made for the increase of about 27 per cent. in the head, and to this end special model tests were carried out to get the most suitable characteristics for the runner. This is 3·35 metres (11 ft.) diameter, and is fabricated by welding the pressed vanes to the crown and rim.

The spiral casing is of welded construction, as are the top cover and general turbine parts. A cylindrical steel support is provided for the generator, enabling its load to be transmitted via the speed ring to the foundations. Inlet valves of 3·35 metres (11 ft.) bore are provided, and are of the "straight-flow" type, similar in design to those at Castelo do Bode, but with due allowance for the increased head. The disperser valve is 3·0 metres (9 ft. 10 in.) diameter, and is capable of discharging 200 cu. metres (7,000 cu. ft.) of water per second.

Both generators are exactly similar to those at Castelo do Bode, but are rated to give a maximum continuous output of 61,000 kVA at 0·892 power factor, corresponding to the maximum turbine output. The generating voltage is 15,500 volts, and both machines are enclosed and self-ventilated, carbon dioxide fire protection equipment being provided. The thrust bearing is of the tilting-pad type and is mounted above the rotor.

Transformer equipment consists of three-phase units rated at 61,000 kVA, with a voltage of 15·5/165 kV. Cooling is effected by the circulation of oil through water-cooled coolers.

The two generators are connected solidly to their associated transformers and the switching is

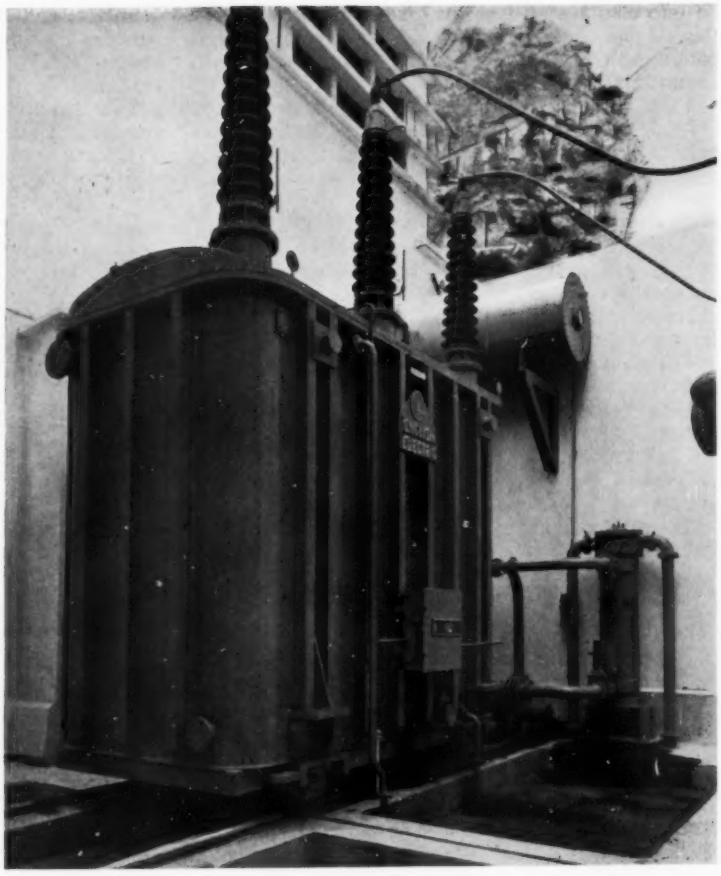


Fig. 3. One of the 61 MVA 15·5/165 kV transformers

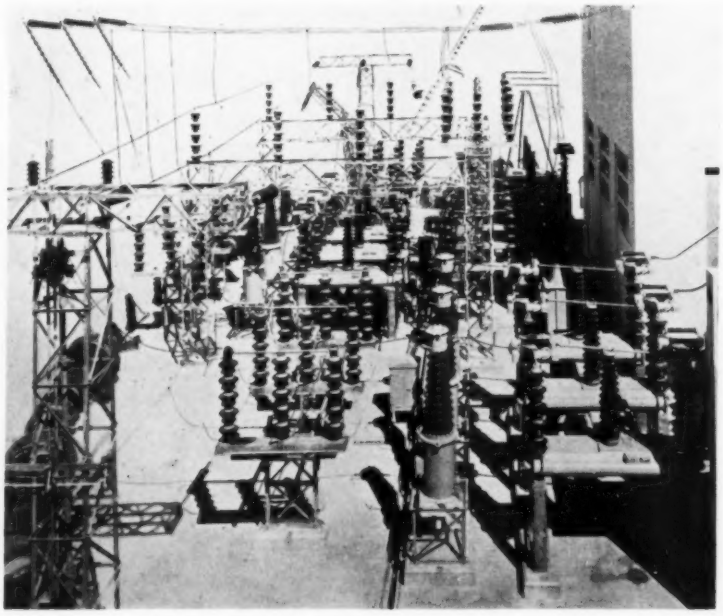


Fig. 4. A view of the 165 kV outdoor substation

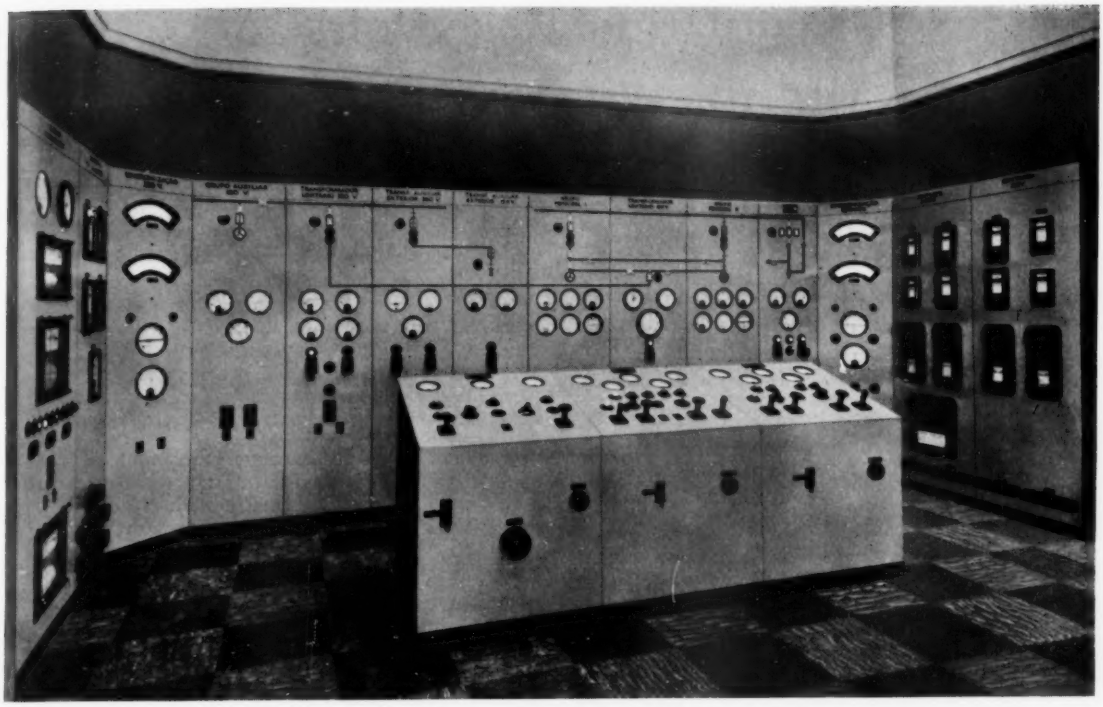


Fig. 5. Inside the control room at Cabril power station

carried out at 165 kV. The high voltage switchgear is of the air-blast type similar to that at Castelo do Bode, with a rating of 2,500 MVA at 165 kV, the feeder circuit breaker being equipped with high-speed reclosure.

A 380 V auxiliary supply is available from three sources—the unit transformer, the auxiliary generator and the station transformer (the last-named deriving its supply from an external source), and is distributed by 1600 A and 600 A air-break circuit breakers in conjunction with metal-clad fuse switch units.

Included on the main control board is an illuminated mimic diagram of the 165 kV, the 15 kV and the 380 V systems. Automatic synchronising equipment is provided for starting up, and automatic voltage regulators control the machines while on load.

The generator and transformer units are protected separately by biased differential protection. The generators also have over-voltage with back-out over-current protection. and the transformers have Buchholz and oil and winding temperature devices, with back-up earth fault protection. Surge protection of the outgoing 165 kV line is provided by 165 kV Metrosil units.

The turbines, straightflow main inlet valves, disperser valve, generators and transformers have been supplied by The English Electric Company Limited, Stafford, whilst the control gear, low tension switchgear, cabling, and the 165 kV switchgear with air-blast circuit breakers, at the substation, have been supplied by the Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester.

Scottish Hydraulic-Machinery Laboratory

The hydraulic machinery research laboratory established in East Kilbride by the Department of Scientific and Industrial Research as part of their extensive programme in that new town, came into use on December 6. Two sections have gone into use covering problems of oil mechanisms and airflow; the third section which will cover research on water flow will become operative at a later date. An important aspect of this development is the care which has gone into the design of the laboratories, after intensive inspection and consideration of similar units throughout the world. The buildings are essentially functional and are regarded as providing an ideal background against which the research work can be carried on. This hydraulic-machinery division unit is the second of seven research units which will eventually be housed at East Kilbride in completion of a plan announced some years ago; the work is of particular importance to Scotland in that many of the problems are of prime importance to the heavy industry in the central belt of Scotland. On the oil side the hydraulic laboratory will deal with hydraulic transmission, the entire sphere of pumping, the operation of presses and forging machinery. Water-turbine research will also be of particular interest to Scotland in view of the steady expansion of hydro-electric schemes there. Model research will feature largely in this section. Dr. S. P. Hutton, head of the Fluids Division of the Mechanical Engineering Research Laboratory of the D.S.I.R., is in charge of the new laboratory.

Reregulating Reservoirs for Multiple-Purpose Projects

The value of reregulating reservoirs in improving the position of power in multiple-purpose projects is explained, and the possibilities of systems of this character are demonstrated by worked examples.

By GEORGE A. WHETSTONE, Ph.D.,
Texas Technological College.

REREGULATING reservoirs have been placed on a number of streams deliberately. In many other cases reregulation has been a fortuitous by-product of further development of the stream. Usually such considerations as dam sites, value of stored water, etc., will have preponderant influence on the size of reservoirs to be constructed, and seldom will a dam be designed just to meet the theoretical needs of reregulation. On the other hand, a knowledge of these requirements may permit the designer to improve the economic efficiency of a project very materially by a small increment in cost. Before concentrating on the methods of calculating volumes of reregulating reservoirs, however, it would be well to explain their purpose and to relate this special problem to the general field of reservoir design and operation.

In general, reservoirs are constructed for one or both of two conflicting purposes—flood control or water conservation. A reservoir, or that part of a reservoir, dedicated to flood control should be allowed to flow to waste as fast as the downstream channel can safely pass the water. In a sense, then, a flood-control reservoir reregulates the natural flow of the stream. However, such reservoirs are not included in the usual meaning of the term "reregulating reservoir" and we may drop flood control from further consideration in this paper.

Water conservation includes a number of uses such as power, domestic supply, irrigation, navigation, and recreation. With good operation schedules many of the apparent conflicts in these uses may be resolved and the same volume in the reservoir may serve one after another of these purposes during the year. Even better, the same water may be required to serve two or more uses in turn. Thus water held in a reservoir has recreation value and serves to maintain head for hydro-electric power. At twice the head, the same flow of water will develop twice the power. After release from the power house the same water may increase channel depths permitting navigation of reaches of river otherwise too shallow through much of the year. Downstream diversions may lead to municipal or industrial use with the effluent being salvaged for irrigation.

Not often is a project this complete, but combinations of power with irrigation, navigation, or domestic water supply are very common. The purpose of a reregulating reservoir is to improve the effectiveness of dual use for power and any other purpose. Water used for power generation has not been destroyed; it has merely given up some of its energy. Thus the total volume available for other use is unchanged.

The flaw in this beautiful picture is that the timing for power releases may not accord well with the timing of releases for other purposes. This timing problem may often be adjusted by the construction of a second reservoir downstream of the first with sufficient volume to allow the power plant at the upstream dam to meet its requirements, with releases from the lower dam being scheduled to meet downstream water-right demands. The lower dam may or may not include a power plant, but if it does this power plant would have little independence of action.

Formulae and "typical solutions" have little place in water-power engineering. They may, of course, be derived on the basis of any set of assumptions made, but the assumptions are seldom valid for more than one site. On the other hand, certain elements occur in most power problems, and by a judicious evaluation of them, with the site always in mind, reasonable mass diagrams and hydrographs may be constructed which in turn lead to the economical and structural planning for development of a given site.

It is seldom that power considerations can be permitted to dominate a multiple-purpose project—and, fortunately, they seldom need to. The first phase of designing a project with reregulation is to design the main reservoir for its non-power use or uses. In this part of the design, of course, preference should be given to sites making large heads available and to those having good sites for reregulating dams downstream. An outflow hydrograph for the main reservoir, neglecting power, may then be prepared. This may take many shapes depending on the percentage of the annual inflow that can be accommodated and on the purpose of the reservoir. Domestic and navigation uses tend to be fairly uniform; irrigation would be highly seasonal. It thus appears that many an existing reservoir may have its power performance improved by the addition of a reregulating reservoir as an afterthought almost as well as if it had been contemplated in the original design. This hydrograph in which power is neglected becomes the outflow hydrograph for the reregulating reservoir.

The next step is to take this hydrograph, which could be expressed in such units as cubic feet per second or acre-feet per day, and, using the volume-

head relations obtained from a survey of the reservoir, convert this to kilowatts or kilowatt-hours per day through use of the relation

$$HP = \frac{Q w h \eta}{550} \quad - \quad - \quad - \quad (1)$$

where HP is horsepower (1 horsepower=0·746 kilowatts), Q is discharge in cubic feet per second, h is head in feet, and η is the overall efficiency from headwater to tailwater. Next, taking such time units as seem convenient (a day or a week usually), we may rearrange the total number of kilowatt-hours during this time into the most useful pattern on the electric load curve.

The water requirements for this part of the load curve would then be superimposed on the outflow hydrograph. The areas on the hydrograph where one curve is above the other then represent volumes stored or withdrawn from storage as the case may be. The algebraic sum of these volumes over a design period is, of course, zero. The greatest unbalance over any consecutive part of the period is the required minimum volume for the reregulating reservoir.

An Illustrative Example

To illustrate the principles, let us consider a flow from the reregulating reservoir at a constant rate of 1,000 cusecs, an efficiency from headwater to tailwater of 82·5 per cent., an average head during the day of 50 ft., and let us take the period of study to be one day. From equation (1) we could produce 3,490 kW or 83,800 kWh per day. The discharge hydrograph would be the horizontal straight line of Fig. 1.

Let the system load curve be represented by Fig. 2. Here area *B* represents the only possible hydro contribution to the system if it were required to develop the power at a steady flow of 1,000 cusecs. This will be recognised as the traditional place of run-of-the-river plants on the load curve.

Usually it would be much more advantageous to shift the hydro contribution to position *A* on the curve since water-power efficiencies are much less sensitive than are steam power efficiencies to changing loads. If we assume that this is what we wish to do, we may reconvert area *A* to reservoir volumes and superimpose it on the hydrograph, Fig. 1. This gives Fig. 3.

From Fig. 3 it may be seen that emptying of the reregulating reservoir begins shortly after 10 p.m. and extends until shortly after 9 a.m. with a total volume of about 33,800,000 cu. ft. being withdrawn. Storage of about 1,650,000 cu. ft. takes place on the morning peak and then withdrawal of about 1,080,000 cu. ft. is made. The evening peak then brings the reregulating reservoir up to maximum level. The storage requirements in the reregulating reservoir for this day are thus 33,800,000 cu. ft.

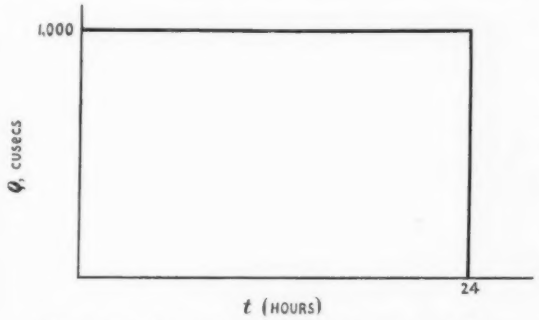


Fig. 1. Discharge hydrograph for constant flow

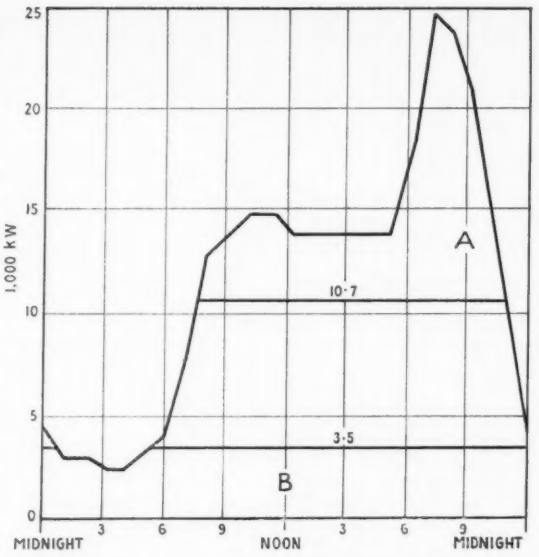


Fig. 2. Typical system load curve, using hydro power for base load

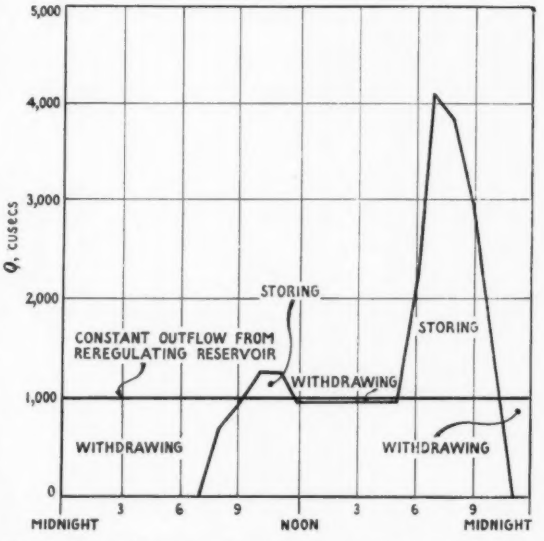


Fig. 3. Flow diagram using hydro power for peak load

In this example we have neglected a number of refinements which would figure in a final design. First, the head does not remain constant but varies with both upstream and downstream reservoir levels. Especially if the surface area of the reregulating reservoir is small this factor may be of sufficient consequence to affect the design.

Second, evaporation and seepage have been neglected. Their effect would be to destroy the equality of inflow and outflow. Surface inflow to the reregulating reservoir would behave in the same manner.

Third, the efficiency does not remain constant but varies with the discharge and head. Thus, if we were

to install a single 15,000 kW Francis turbine to handle the peak represented by area *A* in Fig. 2 the unit would operate sixteen hours a day with all but about four hours of this time at less than 50 per cent. of rated load. Practically, two good solutions to this problem of light loads exist. For the curve in question, three 5,000 kW units, one operating sixteen hours, one operating five hours, and one operating three hours a day would carry the load in the range of good efficiencies. Alternatively, one Kaplan turbine at 15,000 kW rated capacity would provide good efficiency in this situation.

Fourth, the load curve takes various shapes throughout the year, that of Fig. 2 being for a winter weekday. The summer curves and the Sunday or holiday curves may be quite different. Since the water-release curves may also be different it is necessary to be sure that the design is based on the time of greatest storage requirements.

It may well be that economic or geologic conditions at the site would render the solution found in the above manner impracticable. In such a case the kilowatt-hour equivalent of the greatest reservoir volume reasonably available may be placed on the load curve and the distribution of capacity between the hydro-electric plant at the reregulating reservoir and the other plants in the system could be determined.

Pumped Storage

By combining a reregulating reservoir with provision for pumping we may still further enhance the economic attractiveness of a hydro-electric installation. Thus, returning to Fig. 2, it is evident that our sample system must have 10,700 kW of capacity in plants other than the hydro plant under discussion. If this capacity were in steam plants, as it might well be, the cost of running continuously at 10,700 kW would be very little more than the cost of the regime under *A* in Fig. 2. By running at 10,700 kW in the steam plant continuously we would generate between 10 p.m. and 8 a.m. about 56,300 kWh of unmarketable energy which could be employed in pumping water from the reregulating reservoir back into the storage reservoir. With a pumping efficiency of 80 per cent.[1] this would lift a volume of water equivalent to 440 cusecs continuously back into the reservoir. We could thus reduce the discharge from the reregulating reservoir to 560 cusecs and fulfil the same place on the load curve as we did with 1,000 cusecs before installing the pump.

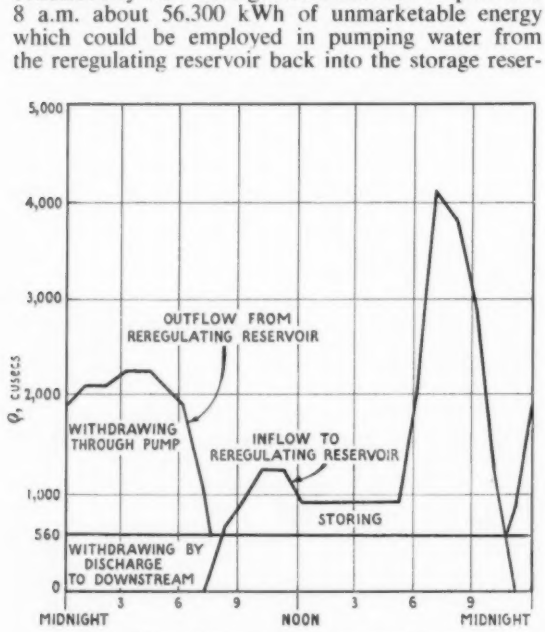


Fig. 4. Flow diagram using pumped storage

The reregulating reservoir would now have its volume calculated as shown in Fig. 4. It is evident that the provision for pumping requires a larger reregulating reservoir.

Modifications of the pumping regime suggest themselves immediately. Thus instead of discharging 560 cusecs to downstream, we may discharge only what downstream water-rights demand by increasing the capacity of the steam plant and then operating at some calculated rate greater than the previous 10,700 kW. It is, in fact, perfectly feasible for an electric power system having no hydro-electric plants and no dependable water supply to obtain the advantages of an efficient peak-load plant by adding a hydraulic pumping plant which operates between two reservoirs adding only enough water to compensate for evaporation and seepage losses. In such a case, it is not necessary that the reservoirs be in a river bed or that they have any natural drainage area.

A glance at equation (1), however, shows the importance of getting as great a head as possible for such a system. Thus, if in our example, we were to substitute a 500 ft. head for the 50 ft. head, the discharges, and hence the volumes, required for the same power would be only about one-tenth as great.

Enough has been said to indicate the principles of design. The actual solution to be adopted in any case must be found with all the limitations of the site and of the existing and anticipated generating plants and load curves of the interconnected system in mind.

REFERENCES

[1] The following figures for efficiencies are given by Mr. G. E. Schmitt for the pumped-storage plant at Buchanan Dam, Texas, in his paper: "Pumped Storage Installation," AIEE Miscellaneous Paper No. 49-126.

Turbine efficiency - - -	91·2%	
Pipeline efficiency, generating -	99·175%	(3 turbines)
Overall generating efficiency -	86·3%	(computed)
Pump efficiency - - -	89·0%	
Pipeline efficiency, pumping -	97·6%	(1 pump)
Overall pumping efficiency -	82·6%	(computed)
Overall efficiency of pumped-storage operation - - -	71·435%	

From page 14

increase the advances it is necessary to keep the hole scatter within narrow limits. The writer's procedure in basing his calculations on a scatter value of 0·01*H* in homogeneous rock is justified by the fact that this exactitude can, and ought to be reached—on the other hand, also by the fact that in drilling by hand the spread can only be reduced to any appreciable extent below this value in exceptional cases and at any rate one cannot base an improvement in method on it.

However, with the help of suitable alignment arrangements, rigid drilling stands and guiding of the drill even in the rock, it is also obviously possible to secure in continuous work a precision in drilling of an exactitude previously unknown, and that with such precision drilling a technique of extraordinary importance for further development in drilling and blasting will become available.

(To be continued)

Engineers and Geologists

This article discusses the relationship which has sprung up between engineers and geologists, with special reference to the hydroelectric field.

By Dr. J. E. RICHEY, B.A.I., F.R.S., F.S.E.

OF recent years a combination of engineering and geology has produced that new professional type, the engineering geologist. An alliance between engineering and geology is really of long standing, however, as an engineer who has to deal with rock and soil has necessarily to be something of a geologist. The first notable engineer of this type was William Smith, the "Father of Stratigraphical Geology," who established the greatest of all the foundation principles of geology in England towards the end of the eighteenth century. In his many excavations for canals and other engineering works he discovered that strata could be correlated with equivalent strata over very wide areas by means of the fossils they contained.

But long before William Smith's day, there were builders, tunnel excavators and the makers of roads and surface aqueducts who must have acquired a certain amount of geological knowledge. Roman engineers, for example, drove a tunnel three and a half miles in length through limestone for draining Lake Fuchino in Italy. They were aware of the properties of limestone, using an acid (vinegar) to cool and break up the rock of the tunnel-face which had previously been heated by fire. That the excavation took eleven years and thirty thousand workmen to complete cannot be attributed to the Romans' lack of knowledge of geology. Still, achievement has lagged somewhat over the years through want of expert guidance, and three broad stages in the relationship between engineering and geology may be recognised. In the first, we find the civil engineer acting as his own geologist as best he may; in the second, after the science of geology had taken a definite shape at the turn of the eighteenth century, the geologist in his own right becomes an occasional collaborator; the third stage had its beginnings in the present century with a more or less close partnership between the two professions.

These three stages can also be discerned in other branches of engineering. They are very apparent, for instance, in mining. The structure of rocks is of as much practical importance as their composition, and the miner was forced to consider both. Many geological terms in common use, such as throw and hade, have thus originated with the miner. In the first stage, the miner was essentially his own geologist, and this continued, with some exceptions, up to near the close of the nineteenth century, for the geologists who followed William Smith's discoveries were not much concerned with practical issues. Subsequently the collaboration between the mining engineer and geologist became more frequent until, in the third stage, it became customary. This partnership was finally established in Great Britain when the duty of examining mineral borings was assigned by Act of Parliament to the Geological Survey, and was finally sealed when the Coal Board employed their own geologists, working in conjunction with the Survey. In petroleum engineering, the first and third stages are well marked, with a rapid transition between the two. When unaided by geology, oil companies often drilled in a very haphazard manner, inspired by the lucky strike of an oil well by "Colonel" Drake's famous find in Pennsylvania at a depth of only 69 ft. in the year 1859. The many failures which resulted from such "wild-cat" drilling led to the full-time employment of geologists, as it was gradually appreciated that the location of oil was dependent mainly upon geological structure, and that the recognition of likely areas for oil was a mere preliminary to its actual location. It was recently estimated that "wild-cat" drilling in the United States showed only 5 per cent. of successful holes, whereas drilling based on geology, combined since about the year 1930 or thereabouts with geophysical methods, shows 23 per cent.

The extent to which the geologist can be of practical use to the civil engineer must necessarily vary with circumstances. In the second stage, with the geologist as an occasional collaborator, and even in our own times, the geologist is often called in only when a difficulty has arisen or after disaster has occurred. In the case of hydro-electric schemes, with their varied calls upon geological factors, the need for co-partnership soon became apparent. Many disasters could have been averted if a suitably qualified geologist had been consulted—the most striking case probably being the failure of the St. Francis Dam in California in 1928. There, a conglomerate forming one of the abutments was so ill consolidated that it disintegrated

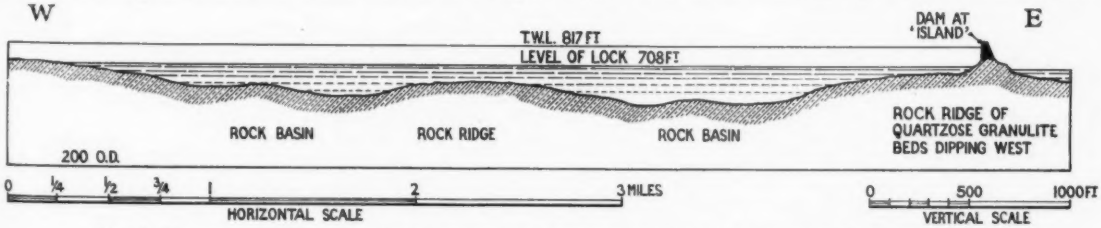


Fig. 1. Uneven erosion of valley floor by ice, forming rock basins separated by rock ridges

when immersed in water. There are also cases, let it be said, where a geologist has failed to recognise a major difficulty and the engineer has suffered in consequence.

One difficulty in the partnership is the very different methods of approach used in these two branches of technology. It is essential not only for the geologist to understand in detail the points of view and the requirements of the engineer, but also for the engineer to be able to understand and to examine critically the geologist's methods of working and the results he puts forward. The geologist's part is to state the circumstances as they will affect the engineer's requirements; the engineer's to deal with them, and upon the latter is laid the main responsibility for success or failure. Geology, moreover, is a science in which the human factor plays a major part. Like science generally, it consists of the observation of facts, the drawing of limited deductions from those facts, and of a synthesis in which one or more limited deductions are utilised for building up an all-embracing theory, or for making wider deductions. But in geology, the observation of facts is not just a matter of observing the result of a single, restricted laboratory experiment, but of an extended series of effects brought about by natural forces acting over and under the surface of the earth during aeons of time. The geologist, in his relation to engineering, has to fix his attention not on all the facts of observation which might accrue from his examination but only on those which he considers to have a bearing upon the engineering requirements. There is room for much choice and, therefore, for error. An essential fact may pass unobserved, or the rock material concerned may be misread either at the observation stage or when the limited deductions are drawn from observations. As a simple example let us take the occurrence of boulder clay at the surface of an engineering site, such as a dam. That this deposit is of glacial origin, that the particular material is tough, clay-like and impermeable, that it lies on the slopes on one or perhaps both sides of the site, as well as along the river itself, may be easily ascertained facts. But that it extends without change of character down to rock-head cannot be assumed without proof by boring or sinking pits, or after exploration of the neighbourhood by the geologist. The instance may seem an over-simple illustration, but it should be recalled that many dams founded on boulder clay in earlier days failed because the engineers were not aware that permeable sand and gravel intervened between the boulder clay and rock-head. Were a geologist to state that such a site was safe, it is for the engineer to ask him, like an opposing counsel examining a witness, "How do you know?" The main responsibility rests with the engineer.

Fig. 2. Trench for cut-off, Pitlochry dam, looking towards river

There is a further difference between the work of the geologist and that of the engineer. In most cases the geologist works alone, and necessarily so. In his work in the field he has constantly to base further search on some observation he has made, and the distraction of a companion may interrupt the follow-up of an idea, or indeed prevent the birth of an idea which an observation might suggest. This isolation is not without its disadvantages. The engineer on the other hand does not work entirely alone, however much he may bear the responsibility for plans and decisions. Both time and opportunities for discussion with his fellows are usually available to him. Something approaching the engineer's advantages in these respects is desirable for the geologist. He, after all, is dealing with much less exact criteria than the engineer, and is more of a plodding worker, limited in the tools he employs, of which his past experience and his eyes are the chief. In view of the dire results which may follow should the geologist be at fault, the engineer should not hesitate to call for a second opinion in cases where he feels himself in any doubt. This is merely what our leading scientific societies do in the case of papers submitted to them for publication, in that it is customary to require favourable reports from

two separate referees, both expert in the subject concerned, before a paper is accepted.

In the United States, partnership between the two professions followed upon the occurrence of many preventable disasters and, more positively, upon notable help given by certain geologists to the engineer. An apposite case of successful collaboration between the two professions was that of the Catskill Aqueduct, for which Dr. Charles Berkey was the geologist concerned. The aqueduct brings water to the City of New York from the Catskill Mountains some 140 miles distant, and the project included not only the driving of a pressure tunnel under varying thicknesses of superficial deposits and through a highly varied succession of rocks and geological structures, but also the crossing at much greater depth of a large river, the Hudson, under which the bottom of the rock-valley was found to be buried to a depth of over 750 ft. beneath a variety of alluvial deposits. There can have been few awakenings to the usefulness of geology more effective than that which this and other work of Dr. Berkey produced upon the minds of American engineers. Indeed, it is understood that, in addition to the employment of ordinary geological methods, a geophysical survey is now run over all important engineering sites in America as a matter of normal practice.

In the British Isles, reliance upon geological advice has become more general during recent years, and in the case of hydraulic schemes an initial geological report is usually obtained. The association of engineer and geologist, however, has not proceeded beyond the stage of occasional partnership, except in the case of certain firms with whom geologists are continuously employed. A firm specialising in a single or related branches of engineering may find this type of partnership to be sufficient. On the other hand, it can rarely suffice by itself to cover the many and varied geological situations which the hydraulic engineer encounters, unless his work is restricted to a limited range of geological environments. Few geologists can be expected to be experienced in all the branches that a civil engineer may require, and it has often been the practice to call in the help of external geologists for collaboration. Such institutions as geological surveys and universities specialising in particular aspects of geology can often be of service in this way.

In the case of recent hydro-electric projects in Australia, such as the Snowy Mountains scheme, geologists form an integral part of the staff. Their work is maintained continuously from the reconnaissance stage, with its preliminary reports, through the site-exploration stage up to the excavation and constructional stages of dam sites, tunnels, sites for power stations and other works. Geological information gained as the work progresses must certainly not be the least of the advantages that this procedure has for the general well being of the undertaking. Even for power-station sites geological factors play a part, and in the case of underground stations hewn out of rock the work of the geologist is often very necessary.

Fig. 3. Trench for Errochty dam in course of excavation

Broadly there are four stages in the work with which the geologist is concerned in engineering projects. Of special importance is the reconnaissance stage, and for many undertakings this is the only one for which expert geological help is obtained. The various stages are well illustrated in hydro-electric schemes, as these are the most comprehensive civil engineering undertakings being pursued at the present time.

Geological Reconnaissance

While it is difficult to lay down specific rules for reconnaissance, it may be stated in general that individual work both by the engineer and geologist is required, and that this should be preceded and followed by full collaboration between them. There are many instances of hydro-electric schemes which were planned by the engineer and in which no major changes were required by the geologist. Others have been modified after the geologist has carried out his examination and discussed his results with the engineer. Others again have been found to have major geological difficulties, but these have had to be overcome by the engineer as best he could, because no other course was

possible without detriment to the scheme as a whole.

These three kinds of circumstance are illustrated from schemes in the Scottish Highlands with which the writer is familiar. On the whole the recent glacial climate of that region has favoured the hydro-electric engineer. Because of the unequal erosion of this region by ice, the valley floors consist of rock-basins which are bordered downstream by well-exposed rock-bars, and the latter have been utilised frequently for the sites of dams.

The site of the Mullardoch dam represents such a case, the loch of that name occupying a rock-basin and extending up-valley for nearly four and a half miles. The rock-bar was formed of that reliable metamorphic rock, recrystallised sandstone or quartzose felspathic granulite, with the bedding dipping directly up-valley (Fig. 1). The bar was breached by two outlet rivers, leaving an island of rock between. Upon this site a gravity concrete dam, 116 ft. in height, was constructed to form the main reservoir for the Affric scheme, designed to produce 230 million kWh per annum. The geological reconnaissance disclosed no major difficulty, although an undetected deeply decomposed basic intrusive sheet at one side of the island gave some trouble during the excavation stage.

There are few cases in the Scottish Highlands where geological difficulties by themselves were so extreme that an alternative site had to be found. Perhaps the siting on the banks of Loch Lomond of the power station for the Sloy project is worth referring to. In this case two alternative sites were selected by the engineers. The first to be investigated involved a shorter pressure tunnel and an even gradient for the pipeline, among other desiderata not present at the second site. But borings revealed thick alluvial and morainic deposits lying upon a rock-surface sloping steeply towards the loch. The foundations were therefore unstable. At the alternative site an initial geological opinion was available, and though the hollow concerned was also covered with superficial deposits, it was possible from local observations of the rock slope to predict a rock-platform at a depth of only about 10 ft. below the surface. This was subsequently found by boring to be the case.

An instance of a dam site where major geological difficulties were indicated by the preliminary geological examination and where the dam was integral with the power station is evidenced by the Pitlochry scheme. This was designed to form the final reservoir of a series of hydro-electric stations making up the Tummel-Garry scheme. Like so many dam sites, there was one fairly good bank where rock could be predicted at a reasonable depth for the abutment, and a very difficult bank where surface deposits consisted of extensive terraces of fluvio-glacial sand and gravel. In spite of this adverse circumstance, the dam was constructed but entailed a cut-off wall through the permeable deposits having a length of no less than 900 ft., and requiring a depth of excavation varying from about 70 ft. to a maximum of 140 ft. (Fig. 2).

Site Exploration

In reports giving the results of geological reconnaissance work, recommendations are made as to the exploration of sites by boring or other means. These amount usually to the minimum requirement envisaged by the geologist for deciding issues about which he is in doubt. Additional bores may be desired by the geologist after he has assessed the significance of the preliminary holes. Generally, many more bores than this geological minimum are arranged for by the engineer for his own purposes. Usually the sites of dams and power stations are the only places where exploration of this kind is necessary but it may be required for pressure tunnels, where the amount of rock-cover is not known from surface indications or where some ancient deeply buried river-channel, or ice-eroded rock-basin, is suspected.

No two sites are similar or call for exactly similar procedures and treatments. Two cases only, both sites of dams, will be cited as illustrations. In a metamorphic terrain, where ancient residual soils and weathered rock have been removed by glacial erosion, such as in the Scottish Highlands, exploration of a dam-site by boring or other means is not usually a major enterprise, unless moraine and fluvio-glacial gravels, etc., are present. In an otherwise favourable environment, however, there are cases where an unsuspected difficulty has turned up during the excavation stage. For example, at the Errochty dam of the Tummel-Garry scheme, at a slightly bulging hillside forming one abutment, the rock was found on excavation to be traversed by extensive cracks filled with fine sand, silt and clay in thin alternating laminae. Similar cracks have also been encountered at other dam sites in the Scottish Highlands which were likewise not known until uncovered in an excavation. If the infillings are permeable, as at Errochty, they have to be washed out by pressure jets of water and backfilled with concrete, or preferably the excavation is taken back to sound rock beyond the fissured zone. The open fractures are caused by the incipient plucking action of ice under pressure, the ice forcing itself into crevices and prising off great masses of the rock in this way. It is one of the ways in which ice carries out erosion and is liable to affect just those narrower places along a valley where a dam is best sited. Such an untoward circumstance can only be discovered by close boring along the sides of a projected site. So far no instance has been found of the floor of the valley being affected in this way.

Sedimentary and also volcanic rocks often call for much subsequent research, after the preliminary geological report. For example, the need for tracing the course of underground water in limestone is insistent in cases where extensive solution cavities in this rock are suspected. In recently glaciated country, in cases where pre-glacially formed cavernous rock has been removed by the erosion of the ice, the time factor may not have been sufficient for extensive new cavernning to have occurred. Underground movement of water along enlarged joint fissures may be transverse to the valley and not thus create the conditions for leakage that would be likely to occur if they ran laterally along the valley sides. In other types of rock, boring may be only a first stage in a prolonged investigation of a site. As an instance a canyon site, the Conchas gravity concrete dam in New Mexico may be mentioned. There the strata consisted of slightly tilted alternating groups of water-bearing sandstones and almost impermeable though fragile red siltstones. The main problems for evaluation were concerned with the amount of settlement of the siltstones under the weight of the dam, leakage through the sandstones from the reservoir, and uplift pressure exerted on the dam due to water in underlying sandstone. A number

Fig. 4. Quartzite rock showing filling (enclosed in boxes) of laminated sand, silt and clay, forced into crevices by the action of ice; north abutment of Errochty dam

of various tests were made of material collected at a number of places across the site in addition to detailed consideration of the site itself. Tests carried out on the siltstones included over 200 unconfined compression tests, 53 shearing tests, the determination of the percentages of clay, silt and sand in these rocks, and the percentage of voids. For the sandstones, the percentage of voids was also determined, as well as permeability both across and along the bedding. Measurements were also made of the flow of artesian water in the sandstones from bore holes. Mr. Irving Crosby jun., the consulting geologist concerned, remarks that, extensive as were these tests, questions such as plastic flow of argillaceous rock such as the siltstones, and expansion and contraction of an aquifer underlying a dam, such as the sandstones, taking place as the level of a reservoir fluctuates, could only be solved by observations at a dam itself carried on over a period of years*.

Excavation

During the excavation of a dam site or tunnel the engineer is continuously on the job, and directs and decides the manner in which the work is done. It is only when some unforeseen difficulty arises that the geologist is called upon for an opinion. Three such examples are described below.

The pressure tunnel leading from the Sloy reservoir to the surge shaft above Loch Lomond encountered a mass of broken rock which proved impracticable to excavate, as roof-falls were too extensive. The geologist concerned, Dr. (now Prof.) J. G. C. Anderson of the Geological Survey, recognised that the broken rock occurred just where two fault-planes met underground. The fault-planes followed slightly different courses and so diverged from one another both laterally and vertically, resembling in section an inverted V or, better, the Greek letter Lambda. The geologist therefore advised crossing the two faults in turn, at places where they did not happen to coincide and where no untoward amount of broken rock was to be expected. This procedure, which entailed making a lateral bend in the tunnel, proved successful.

The second may be best described in words in the Berkey Volume of the Geological Society of America (1950, p. xvi): "During the foundation excavation for Coulee Dam [on the Colorado River] the rock proved to be sheeted in horizontal layers, and progressive excavation failed to disclose any improvement at greater depth. Nevertheless, in the belief that the joints were somehow associated with near-surface conditions, the excavations were continued as one layer after another, resembling the shells of an onion, were removed. Doctor Berkey [on being called in] realised at once that the rock possessed a residual stress and that erosional unloading, aggravated by the excavation itself, was causing the sheeting by relieving the superincumbent pressure and permitting stress

*Amer. Soc. C.E. Trans., 105 (1940), 509.

relief through the formation of 'lift seams.' Accordingly, excavation was stopped, and the dam was built, thus replacing the load which had been excavated from the foundations. Subsequently, the 'lift seams' were grouted under pressure, and the foundation has proved to be both competent and impervious."

The third example, relating to a dam-site on slaty rock at Pinet-sur-le-Tarn, is described by the late Prof. Maurice Lugeon in his book, "Barrages et Géologie" (pp. 34-35). There the slaty beds were inclined on either bank in directions away from the river. In a tunnel within one of the steep valley-sides, however, the rock was found to be much fractured and unstable where the beds, in depth, became vertical. Lugeon recognised that the tilted beds were the result of rock-creep on the steep valley sides due to gravity acting upon the exposed and somewhat weathered ends of the beds, and that fracturing was to be expected where the disturbed beds joined the normal vertical and undisturbed strata. With this knowledge of the situation, the engineers carried out the excavation for the dam by terracing the slopes in a series of steps, and then each terrace was trenched down to sound rock; the dam was thus tied to sound rock and the unsound rock grouted. Lugeon also records instances in the Alps where the disturbed strata extended for more than 100 metres from the surface horizontally and for more than 50 metres perpendicular to the valley slope. He remarks that it is indeed a misfortune if a dam is sited in such a situation.

Construction

To the geologist may, and indeed should, fall the responsibility for locating suitable stone and deposits of sand for the necessary concrete. In his initial report it is customary for the geologist to record any likely possibilities which he may happen to notice during his exploration work. This is often just a first step in what may be an intensive search, as so much in the way of favourable costs depends upon the ready availability of suitable materials.

In the first instance the geologist may suggest that rock spoil from a tunnel may be suitable for both the coarse aggregate and for reduction to the necessary rock-sand. At the excavation stage it devolves on the engineer to consider such a possibility in detail. Seldom, or never, will the entire spoil from a tunnel be of the same quality throughout. Selection is thus necessary, and this may prove too difficult to be practicable. If at all possible the engineer, in collaboration with the geologist, should decide before excavation starts whether spoil is likely to be utilisable or not. Otherwise time may be lost before finding and exploiting some other source.

The main rocks which may be relied upon to yield uniform stone are those of igneous and intrusive origin, such as granite and certain basaltic whinstone, or their metamorphosed equivalents—granitic gneiss and epidiorite. Sometimes the recrystallised (metamorphosed) sandstone called siliceous granulite is sufficiently free from layers of mica-schist, originally shale, to be utilised. In other cases, as in the north of England, hard sandstone (millstone grit) of carboniferous age has been found suitable. In the case of granulite or sandstone rock, the chances of locating a suitable outcrop for open-cast quarrying are naturally much greater than those of obtaining a sufficiently long run of suitable stone (free from mica-schist or shale) from a tunnel.

Hydro-electric projects in the Scottish Highlands have been nearly all situated within reach of suitable stone for coarse aggregate, although in certain cases, as at the Sloy and the Lawers projects, somewhat distant intrusive igneous masses have had to be quarried and the stone transported either by continuous travelling belt or overhead cable. On the other hand, sand has had to be brought by road from distant sources in several cases. For locating stone geologists have proved useful; in the case of sand a few new sources have been exploited, and it is a matter for consideration whether more intensive searches for this erratically placed deposit might not be worth while.

NOTE. The courtesy of the North of Scotland Hydro-Electric Board is acknowledged for the use of the photographs for Figs. 2–4.

Reorganisation of the A.E.I. Group

Associated Electrical Industries Limited have reorganised the A.E.I. companies into four groups: B.T.H. Group, Ediswan-Hotpoint Group, M-V.E. Group, and Overseas Group. The reorganisation, and all consequent appointments, took effect from October 11, 1954. The Chairman of A.E.I. has become Chairman of each of the Groups. The Group Managing Director of the Overseas Group will be Dr. I. R. Cox; he will be the A.E.I. nominee director on the Boards of A.G.E., First Electric and Vecor, and will become Chairman of A.E.I. (India) and A.E.I. (Pakistan). The B.T.H. and M-V.E. Export Companies will operate as at present. To ensure the closest liaison, however, the Group Managing Director of the Overseas Group has become Chairman of the B.T.H. and M-V.E. Export Companies.

Distribution Voltage Regulators. Ferranti Limited, Hollinwood, have published a handsomely printed brochure giving details of their moving-coil voltage regulators for transmission, distribution, industry and laboratories. These regulators have been designed primarily to meet the need for a simple piece of equipment to control distribution voltage near the point of application, and their construction, operation and scope of application are admirably set out in the brochure.

English Electric Journal. The June and September 1954 issues of this journal contain articles giving detailed descriptions of recent hydro-electric developments in Portugal. The September issue, now before us, gives particulars of the Vila Nova scheme.

Sengulam Penstocks. We regret a typographical error on page 438 of our November 1954 issue in giving the name of the makers of the penstocks for the Sengulam project, India. The name of the company is Dortmunder Union Brückenbau AG., Gelsenkirchen.

Deepening a River Bed. In connection with this article, which appeared in our December issue, we regret an oversight whereby the designed flow for the deepened channel of the river Erne was given as 311 cusecs instead of 311 cu. m. per sec. Similarly, the figure of 300 cusecs on page 464 should read 300 cu. m. per sec.

Testing Overhead-Line Equipment

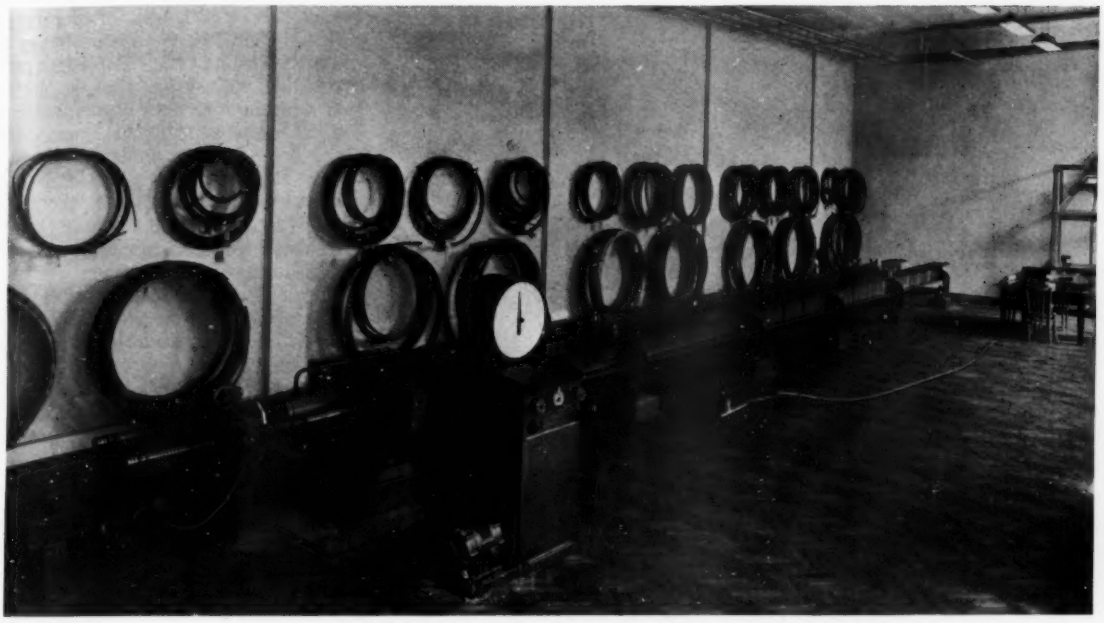


Fig. 1. The 100-ton testing machine for overhead-line joints in the testing laboratory of A. Salvi & Company, Milan

The continual search for new power resources has meant that many remote hydro-electric projects which, until recently, were considered as being on the economic borderline, have now to be brought in to the power-production pool. This means that there is an ever-increasing need for power transmission; and the engineers concerned have continually to cope with greater distances and larger powers per circuit. In addition to this aspect of hydro-electric development, there is a growing tendency to interconnect hydro and thermal power systems, to mutual advantage, and this again involves the lengthening and strengthening of transmission capacity. Incidentally, in the course of a number of recent papers presented to the American Institute of Electrical Engineers and to the Institution of Electrical Engineers in Great Britain, the point has been clearly made that above about 100 miles length, it is cheaper to transmit energy electrically than it is to carry it in the form of coal by rail or sea, or to transport oil by pipeline or tanker.

This development in very high-voltage high-power long-distance transmission lines has resulted in a progressive increase in spans, mechanical tensions and conductor sizes, and this has posed some difficult problems. One of these has been the jointing of the steel-cored aluminium conductors now almost universally used. In the early days of the A.C.S.R. conductor, in about 1920, various types of cone joint were utilised, but they were apt to corrode and consequently to overheat when heavy currents were passed; finally, a number of failures resulted, some with serious and even fatal consequences. The compression-type joint, introduced at about the time of the beginning of the second world war, has proved to be the most satisfactory answer to the overhead-line jointing problem, and variants of the compression joint are now used by electricity supply authorities in very many, although not all, of the highly electrified countries of the world.

The compression joint is not without its own problems. A steel sleeve is compressed over the steel strands by means of a hydraulic compressor, commencing at the centre and working outwards in both directions, first one way and then the other, and then an aluminium sleeve (previously slid over the conductor) is brought into place and is compressed again from the centre outwards. If perfect compression is achieved, a completely homogeneous aluminium section is seen when a test joint is cut through, and it is practically impossible to distinguish where the strands of the conductor finish and the aluminium of the sleeve commences. The compression type of joint is immune from corrosion troubles, but only if properly manufactured and compressed on to the conductor. Here there intervene the problems of casting aluminium joint and dead-end bodies without flaw, and of designing compressor dies and other parts, and these have not always been satisfactorily solved.

In order to prove that a given joint has been properly applied, it is necessary to carry out extensive mechanical testing on a series of joints, and for this purpose it is necessary to use an extremely accurate traction testing machine. In the past reliance has been placed on the type of machine used mainly for the testing of chains and short samples up to about two or three feet in length, but these methods can no longer be considered as satisfactory for the proving of

Fig. 2. Part of the Sluderno-Stelvio-Cesano line running through difficult country. The joints on this line have been supplied by A. Salvi & Company

joints for large conductors, where a length of 20 or 30 ft. is necessary in order that the natural effect of the lay of the strands can be taken into account. Moreover, the power required to break a test sample may reach figures of the order of 100 tons, which must be applied steadily with great accuracy of reading.

What is believed to be the first testing machine in the world designed specifically for this purpose has recently been installed in the Milan works of A. Salvi and Company, and has been specially designed and manufactured by Messrs. Galdabini and Company of Gallarate, Italy. It is depicted in Fig. 1 and is of the hydraulic type, exerting a maximum pull of 100 tons. The stroke of the piston is 1 m. and the total length of the test bed is 10 m., the fixed head having stops every half metre, so that any possible extension of the test piece is allowed for. The dynamometer used for measuring the load is of the pendulum type, and the scale can be read to an accuracy of about 0·01 per cent. The machine is also equipped to carry out endurance tests, for which purpose an automatic adjustment is incorporated to keep the pump so operating as to provide constant load for an indefinite period.

The testing laboratory of A. Salvi and Company, now enlarged by the addition of this machine, already includes X-ray equipment for the inspection of the castings from which the joints are made, and also a number of unique and special testing devices. For example, a vibrating machine has been installed, in which the spring-ring spacers (used to keep apart the twin conductors used on high-voltage overhead lines, and patented by the Salvi organisation) can be subjected to tens of millions of deformations in every direction, in order to ensure that no possible stresses met with during service conditions could result in a permanent deformation of the spacer ring.

Fig. 2 shows part of the Sluderno-Stelvio-Cesano line running through difficult country, in which the reliability of the joints is obviously of paramount importance. These joints are of the compression-type, and were supplied by A. Salvi and Company.

A Departure in Portable Compressors

An innovation in portable-compressor design is to be found in a new series now being made at the Fraserburgh works of The Consolidated Pneumatic Tool Co. Ltd. It is known as the "Power Vane" series because the compressors are of the rotary-vane type instead of the usual reciprocating variety. The principle of the rotary-vane blower and pump, of course, is long established, but we believe that this is the first portable compressor of this type to be placed on the British market. Even so, the series is by no means of an untried design, as units of this design have been built up by the C.P. organisation in the United States for a number of years.

The unit has a low-pressure and a high-pressure cylinder, giving a

The C.P. "Power Vane" 365 cu. ft. per min. compressor

final air pressure of 100 lb. per sq. in. An unusual feature is the use of an oil system not only to lubricate the compressor but also to seal the vane clearances and cool the air. The oil is circulated by a gear pump to the bearings and to the vane cylinders, and is carried by the air to the machine receiver, where most of it is precipitated and drains to an oil tank, the remainder being removed by a separator at the outlet from the receiver. A radiator-type oil cooler is inserted between the oil tank and the gear-pump suction. It is claimed that the air leaves the compressor at least 100°F. cooler than in a conventional piston-type machine, and that the wastage of oil is so low that topping-up is unnecessary.

The compressor is powered by a four-cylinder Rolls-Royce diesel engine, the speed of which is automatically governed in accordance with air demand.

Two important advantages are claimed for the design, in addition to the reduction in final air temperature already mentioned. The first is the reduction of weight, which is as much as 30—40 per cent. on the compressor itself. The second is the reduction in maintenance due to the absence of pistons, piston rods, crankshaft, and valves.

Four sizes of unit are available having free-air deliveries ranging from 125 to 600 cu. ft. per min. The unit illustrated has a capacity of 365 cu. ft. per min. and is less than 12 ft. in length by 5 ft. 6 in. wide.

Precooling Concrete for Vaitarna Dam

An interesting method of cooling concrete is being used in the construction of the Vaitarna dam, Bombay Province. Part of a scheme for almost doubling Bombay's water supply, the dam impounds the flow of the Vaitarna river 75 miles from the city. It is of the gravity type, 1,820 ft. long at the top and 269 ft. high.

Experience elsewhere in similar projects has shown that the tensile stresses in the concrete are kept within safe limits when the difference between the maximum and the stable temperature is no more than 20 or 25°F. At the Vaitarna dam the air temperature varies from 114°F. to 52°F. and the water temperature is 85°F. The final stable temperature of the dam is estimated at 85°F. to 90°F. The temperature rise due to the hydration of cement has been calculated as being about 50°F. above the pouring temperature after about 52 hours of placement. The normal temperatures of the components of the mix are about 100°F. With no cooling the interior heat of the concrete would go up to about 150°F. Therefore to keep the maximum heat to within 25°F. of the ultimate stable temperature the concrete is cooled to 60°F. when poured.

One method of cooling concrete is to build within the structure an elaborate pipe system through which refrigerated brine is circulated during placement followed by water to remove heat while the concrete is setting. A simpler method is used at Vaitarna. After being crushed and screened the aggregates are conveyed on six slow-moving belt conveyors through a cooling tunnel, which is 330 ft. long and cork insulated. In conjunction with this there is a Freon cooling plant having a refrigeration capacity of 650 tons. During transit through the tunnel the coarse aggregates are cooled to about 40°F. by chilled water sprays and inundation, and afterwards passed through a high-velocity blast of moisture-free air chilled to between 40°F. and 42°F. The fine grades are cooled by the chilled air only, the temperature being reduced to 72°F. The mixing water is chilled to 36°F. by the same cooling plant. The cement is not cooled before mixing. The chilled air is circulated by eight Aerofoil fans manufactured by Woods of Colchester Ltd., each delivering 27,500 cu. ft. per min. With this cooling system the temperature of concrete at mixing is 57°F. The pouring temperature is 60°F. and has been as low as 58°F.

Fig. 1. A view of Vaitarna dam under construction. This scheme will almost double the water supply to Bombay

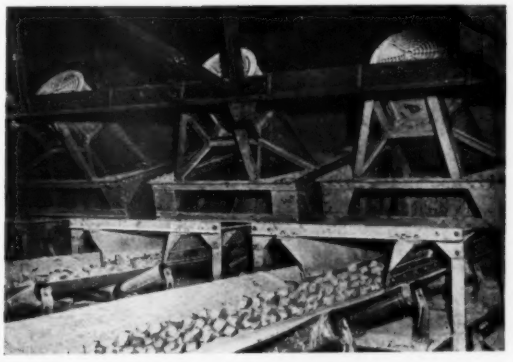


Fig. 2. Part of the concrete precooling plant. The coarse aggregates are cooled by chilled water sprays and chilled air, the fines by chilled air, and the mixing water is cooled by the same plant

Since the commencement of the project in May 1952 over 20 million cubic feet of concrete have been poured and the required placement temperature has been constantly maintained. The cooling system has operated continuously without hitch or failure.

Abstracts from the World Technical Press

Oil-and-Water Seals in Kaplan Runners

This article relates to the oil-and-water seal in the oil-filled hub of a Kaplan runner. The hub of the runner instanced, as shown in Fig. 1, is filled with 3,500 litres of oil for the lubrication of the blade-adjusting gear and of the blade pivots; deficient seals had previously caused a continuous leakage which, at times, reached 100 to 120 l. per day. In addition, the danger of serious corrosion to the mechanism enclosed in the hub, through an inward leakage of water, had to be met, and when measurements had shown that the amount of water inside the hub reached 1,000 l., the turbine had to be stopped, the water drained, and oil losses made good. The first step towards a radical improvement was to discard leather as sealing material, and to substitute a neoprene compound; this seal, with its parallelogram-shaped cross-section (Fig. 1), behaved satisfactorily in warm weather, and the rough contact surfaces did not cause any inconvenience. In winter, however, when water was close to freezing point, the seal lost in elasticity, and its bottom face was lifted by the seal-holding collar, so that leakage again occurred, though to a lesser extent. Nevertheless, neoprene had asserted its superiority over leather, and experiments were continued. The resulting improved seal which is now in use in five of the seven turbines, is shown in Fig. 2. In this the inner face of the seal-holding collar forms a blunt wedge which presses the seal downward against the pivot of the blade as well as upward against the rib of the hub. With this improved seal pattern, leakage is now negligible, even in winter, and even when the contact surface of the pivot is far from being smooth. In No. 6 turbine, a stainless-steel band has been drawn on to the pivot, so as to afford a perfectly smooth seat to the seal. In No. 7 unit, added later, the seal of the blade pivots is quite different and consists of three rings, rectangular in cross-section: an inner ring on the oil side and, on the water side, two rings made of linen fabric with an oilproof rubber core; the seal holding collar has been discarded, and the elasticity of the seal itself, supplemented by adjusting screws leading through the cap of the hub, affords an adequate sealing pressure. It is, however, claimed that the seal fitted to the first five turbines (Fig. 2) is just as efficient in leakage prevention and saves just as much maintenance work. (*Technische Rundschau*, Vol. 46, No. 26, 18.7.1954, p. 3, 2 cols., 4 ff.)

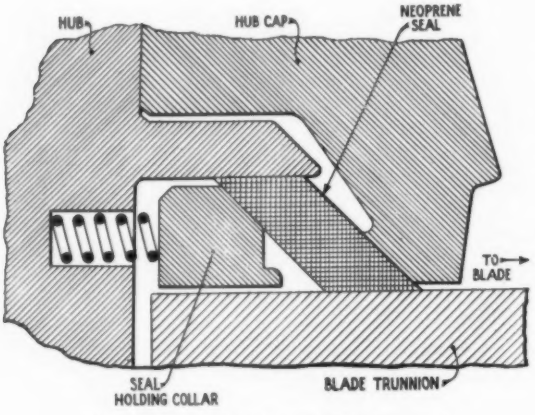


Fig. 1. First redesign of Kaplan seal

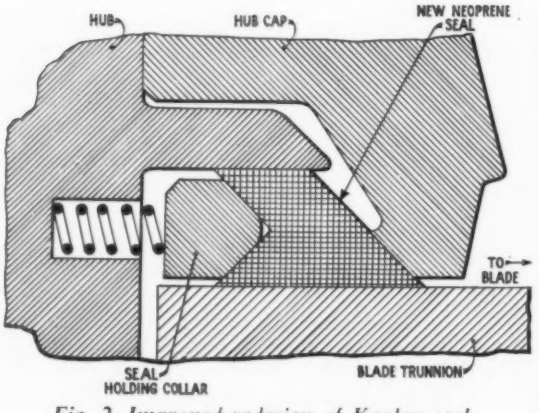


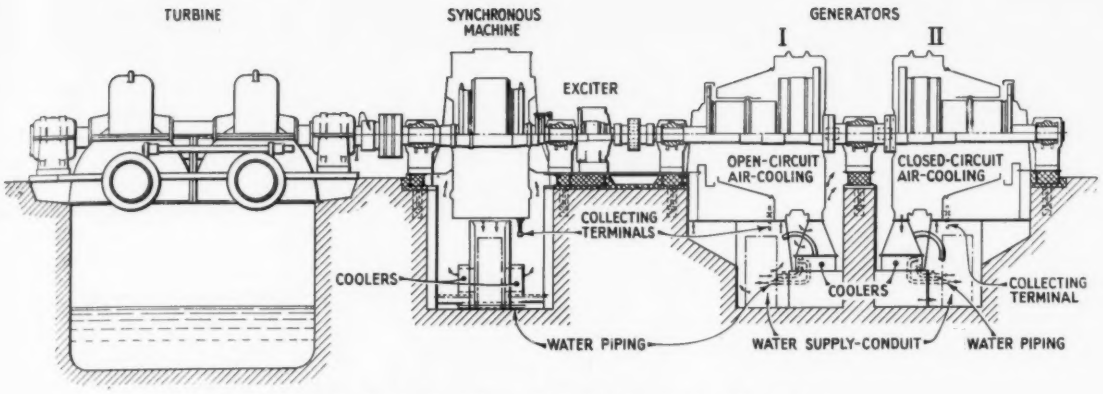
Fig. 2. Improved redesign of Kaplan seal

Sand Trap at Lavey Power Station

The designer of this sand trap, which was described in our issue of May 1951, p. 198, reports on tests carried out at Lavey in 1951 and 1953. This sand trap was built for a discharge of 200 cu. m. per sec. and is giving entire satisfaction; to mention the results obtained in both years during the four summer months only, the amount of material trapped reached a daily average of 1,530 metric tons. The various tables included in the report show that the sand trap retains a large proportion of particles below the 0·15 mm. and even below the 0·1 mm. size. The coarsest particles to reach the turbines consist to a large extent of mica and slate flakes which can hardly be trapped in practice but are unlikely to exert any detrimental effect on the steel components of the turbine. (Henri Dufour, *Bulletin Technique de la Suisse Romand*, Vol. 80, No. 10, 15.5.1954, p. 165, 9 pp., 1 f., 11 tables.)

Ballandaz Power Plant

The generating set supplied by the Ansaldo San Giorgio concern, Genoa, to order of Electricité de France for their Ballandaz plant, presents an uncommon pattern, as shown in the accompanying diagram. It comprises two 1,000 kW 10,000 A dynamos which supply current to furnaces applied to an electro-chemical process, and a synchronous machine which, according to requirements, operates either as a generator, a motor or a compensator. The normal speed of the Pelton turbines is 375 r.p.m. and the runaway speed 680 r.p.m. At normal periods, the set is driven by the turbine and the synchronous machine, acting as a generator, feeds the a.c. system. At low-water periods, the set is driven by the synchronous machine, working as the normal motor of a synchronous converting set, and starting is effected by one of the two dynamos fed from the d.c. system. If required by service exigencies, the synchronous machine can also operate purely as a compensator, in which case it must reach an inductive output of



Longitudinal elevation of Ballandaz generating set

1,700 kVA, and a capacitive output of 1,900 kVA. A full description is given of the electrical components of this set, which has proved very satisfactory under difficult service conditions. (*Notizario Ansaldo San Giorgio*, No. 6, March 1953, 5 pp., 8 ff.)

Tidal Power

The theoretical aspects and the practicability of the harnessing of tidal energy to power generation are discussed, and the various practical solutions contemplated are examined, from the one-basin tide type and tide-ebb type to the two-basin types with the two basins operating either in conjunction or separately. Three variants are considered: (a) independently-operating tidal plant supported by storage facilities; (b) plant working in co-ordination with some other power station; (c) incorporation of the tidal plant in an interconnected system supplying a common grid. The author deals in detail only with variant (a), obviously the most unfavourable, and examines the possibility of supplementing its output by means of either electrical, thermal or hydraulic storage. In the first case the current not absorbed by the network is diverted to storage batteries, and subsequently supplied to consumers when required after passing converters or transformers. In the second case each turbine is coupled to a hydraulic brake in such a way that the water flows from a pressure tank to the brake and then returns to the tank, a throttle in this water circuit enabling the temperature of the water to be raised to about 145°C. By reducing the pressure in the tank, steam can be fed to a steam turbine. Finally, topographical conditions permitting, excess power generated in the tidal plant can be used in large pumping plants feeding storage reservoirs. This is obviously the most favourable solution of the storage problem. The article concludes with a review of various projects under consideration in Europe and America. Among these, the Gulf of San Juan scheme in Argentina is conspicuous by the great number of generating units projected—no less than 376. The gulf is to be closed by a concrete dam creating a basin of 780 sq. km.; the turbines, fitted with rotary ejectors and rotary gates, are to run in the same direction at both tide and ebb periods, and to cope with an aggregate discharge of 90,000 to 150,000 cu. m. per sec. At neap tides, which occur about 10 times every year, it is estimated that the daily output of the plant will reach 15 million kWh and rise to twice as much with the highest tides. (Dr. Ing. G. Wickert, Karlsruhe, *Technische Rundschau*, Bern, Vol. 46, No. 31, 23.7.1954, p. 9, 2 pp., 14 ff.)

Stream-Bed Intakes

This type of intake is the rule when the flow of a mountain torrent has to be collected to increase the water supply of hydro-electric plants; its purpose is to convey the water from the stream-bed over a slightly sloping screen through which water and fine solid matter drop into a collecting pit, while pebbles and larger stones, rolling along the bars of the screen, are diverted. Though dealing with specific conditions, the tests described in this article are of general interest since they were carried out with different types of screen-bars, various positions of the screen in relation to the flow, and various slopes of both screen and supply channel. They can therefore easily be applied to more orthodox types of intakes. The testing arrangement, shown in Fig. 1, represents a 1 : 5 scale model of an intake set up on the strongly eroded bed of a torrent in the French Alps at an altitude of 2,000 m. The main characteristics of this model were: discharge diverted, 3 cu. m. per sec.; screen surface, 2 m. wide by 4 m. long; full-empty ratio, 2·2; gradient, 20 per cent. Provisions were made to ensure a separate slope adjustment for both screen and supply channel, as well as the regulation of flow velocity. Water losses were determined by collecting the water creeping along the bars in a transverse channel fitted under the down-

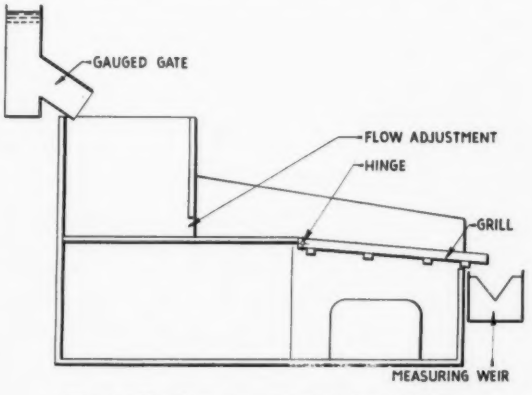


Fig. 1. Testing arrangement for intakes

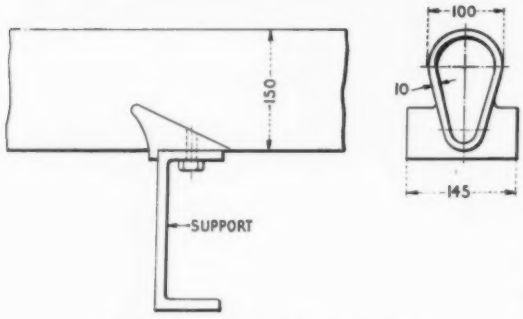


Fig. 2. Streamlined intake bar

stream end of the screen and equipped with a measuring weir. The knowledge gained from these tests is of great practical value. Among other results, it was established that the efficiency of the screens, that is to say, the volume of water they discharge, depends not only on their length but is also closely related to the shape of the bars and their arrangement. The best results were produced by the streamlined type of bar shown in Fig. 2, which restricts the jamming of pebbles, enables the water to flow smoothly down the cheeks of the bar and, in addition, offers at least as much resistance to buckling as rail-type bars. Accuracy between preliminary computations and experimental results proved satisfactory. (J. Orth, E. Chardonnet and G. Meynardi, Electricité de France, *La Houille Blanche*, Vol. 9, No. 3, June 1954, p. 343, 9 pp., 15 ff.)

The Braz Power Station

A full description is given of the underground power station recently put into operation near Braz, Vorarlberg. It is the first of its kind on Austrian territory and will supply power to the electrified lines of the State Railways. The station receives its water from the Alfenz stream and from the tailrace tunnel of the Spullersee hydro-electric plant, and operates under a head of 480 m. The choice of an underground power house was dictated by local conditions, but actually ensures the most advantageous utilisation of the head available. The free-flow tunnel conveying the discharge from the Spullersee turbines expands at its downstream section to form a 310 m. long surge chamber which connects with a three-chamber surge tank about 260 m. in length and 25,000 cu. m. useful capacity. Flooding is controlled by a spillway which returns the water to the Alfenz through a covered channel. A 480 m. penstock, 2,100/1,800 mm. in diameter, with a gradient of 38 per cent., leads from the surge tank to the underground valve chamber and the 1,700 mm. diameter manifold from which three branches feed the turbines. The cavern sheltering the generating sets is 80 m. long, 22 m. wide and 17 m. high. Ventilation shafts, which can also be used as emergency escapes, provide the machine hall with 50,000 cu. m. of air per hour. A 214 m. long tunnel, with a gradient of 13·6 per cent., is accessible to light lorries, and connects the main cavern with the switchgear station at the foot of the hill. The discharge from the turbines flows through a 1·8 km. long tunnel into a 40,000 cu. m. balancing reservoir, concrete lined throughout, before returning to the Alfenz. The excavation of the caverns involved the removal of 350,000 cu. m. of rock, and the aggregate length of the tunnels is 14 km. At a later date the water of the Formarinsee will be diverted to this plant, increasing the output of the Spullersee-Braz group by 60 million kWh. Upon completion of this development the Austrian State Railways will thus have at their disposal a yearly supply of about 160 million kWh, of which 70 per cent. will be available during the winter months. (*Technische Rundschau*, Bern, Vol. 46, No. 31, 23.7.1954, p. 11, 2 pp., 5 ff.)

Silt Deposits in Conduits

An account is given of the observations made in the supply conduit of the Bévercé power station in Belgium, where silt deposits have been found to be the cause of load losses. These investigations were made at the end of last summer, when the conduit was drained to enable maintenance work to be carried out in the steel section of the conduit, which had not been overhauled since 1934-36. No measurements of discharge or head losses were taken. After typical specimens of deposit had been photographed, plaster casts were obtained, and samples of the deposits were taken from various points for the purpose of chemical and biological analysis. Generally speaking, it can be said that the silt is deposited in almost annual layers, and mainly consists of manganous material, brown in colour; the average thickness is practically constant, and the deposits occur in undulations perpendicular to the flow, and varying with their length. At the inside of bends and in branches, deposits are more even, and show traces of drifting. Silt deposition presents a certain analogy with the ripples seen on sandy beaches and the undulations of sand dunes in deserts. The influence of the flow velocity on the length of the undulations cannot be ruled out. Adopting the following symbols: L = length of undulation, i.e. mean distance between two neighbouring crests; h = height of undulation, i.e. mean distance between trough and crest; e = thickness of deposit, i.e. mean distance between the conduit wall and the tip of the crests, the author draws the following general conclusions: (a) the relation between h/L and e/L should be determined; (b) L, as previously pointed out by Escande, might be a function of flow velocity at the conduit wall; (c) the deposits do not collect in a regular and continuous way. (G. Thiessard, *Proceedings of the Société Hydrotechnique de France (La Houille Blanche)*, Vol. 9, No. A, May 1954, p. 266, 9 pp., 15 ff.)

CLASSIFIED ADVERTISEMENTS

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